Report

D1.2 Migration Plan

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Abbreviations

ARCC	Automated Rail Cargo Consortium, S2R project consortium
AWP	Annual Work Plan
BMVI	Bundesministerium für Verkehr und digitale Infrastruktur, German Federal Ministry of Transport and Digital Infrastructure
CA	Consortium Agreement
CBM	Condition based Maintenance
CCA	Cross Cutting Activities
C-DAS	Connected Driver Advisory System
CT	Cooperation tool
CTL	Closed Train Loop (operational mode)
DAC	Digital Automatic Coupler
DAS	Driver Advisory System
EC	European Commission
ED	Executive Director
EU	European Union
FFL4E	Future Freight Loco for Europe, S2R project consortium
FR8HUB	S2R project consortium
FR8RAIL	S2R project consortium
FR8RAIL 2	S2R project consortium
GA	Grant Agreement
GoA	Grade of Automation
IM	Infrastructure Manager
IP	Innovation Programme
IPR	Intellectual Property Rights
IVG	Intelligent Video Gate
LU	Loading unit
MAAP	Multi-Annual Action Plan
NS	Network Statement
OTL	Open Train Loop (operational mode)
P2P	Point to Point (operational mode)
S2R JU	Shift2Rail Joint Undertaking
SC	Steering Committee
SMP	Strategic Master Plan
STI	Safe Train Integrity (system)
TD	Technical Demonstrator
tkm	tonne-km, Tonne-Kilometre
TMS	Traffic Management System
TMT	Technical Management Team
TO	Terminal Operator
RU	Railway Undertaking
UITP	International Association of Public Transport)
WP	Work Package
WPL	Work Package Leader
YM	Yard Manager

1 Executive Summary

The present report “Migration Plan” is going to show ways how to introduce solutions and new technologies under market conditions by clearly describing benefits and availability of solutions for shippers, operators and customers. It also considers dependencies between technologies and solutions in order to develop reasonable migration paths which also have to take into account the financial capacity (limited resources). It is therefore a compilation of relevant technology and innovation paths for European rail freight. The focus lies on a joint perspective of users and solution providers describing benefits of key technologies carried out not only in FR8HUB but also in the other projects of IP5.

The research concludes that the development and implementation of new technologies alone will not be enough to attract additional transport to rail. It will be imperative to change the way services are provided. Contrary to what is often assumed by the sector representatives, the low competitiveness of rail is not due to too high costs and thus too high offer prices. Rather, today's service offer does not meet the expectations of a transparent, flexible and easy-to-integrate transport task. Lack of accessibility to and reliability of the overall system result in poor service quality of rail. The yardstick here is not the system itself, but modern road freight logistics, which have improved enormously in recent decades and today set the standards from the transport customer's point of view.

Rail does not have to compete with road for quality reasons alone. Road also dominates those transport segments that are at all relevant for significant growth and additional market shares for rail, as studies in FR8RAIL have shown.

In this respect, the challenge of the sector is not only to innovate the system technologically, to make loads trackable, etc.; it is also to break with previous beliefs in order to establish new, market-driven and highly utilised production concepts. Taking into account the economic and financial possibilities of the sector, the authors propose a two-part migration approach - consisting of an evolutionary path where previous production concepts are improved through the deployment of new solutions. This essentially pays for single wagonload traffic or traffic that provides for a more or less continuous train configuration along a route. The second migration path has a revolutionary character, breaking with previously mentioned compatibilities to the UIC system, providing for new wagon material in fixed train configurations that can be fitted into a timetable traffic due to higher running speeds and an overall more dynamic running behaviour, thus enabling new production concepts. Both paths are initially followed in parallel over a period of about 20 years, with the initial islands of innovation of the revolutionary approach being continuously expanded and gradually pushing back the current system.

This should not give the impression that the costs of service provision do not play a role. The establishment of new concepts and the introduction of new technologies naturally also serve to further reduce the specific transport costs in order to survive in competition in the long term with expected increases in efficiency in road freight transport.

Chapters 2 and 3 first give an overview of the background and objectives of work package 1 in the FR8HUB project and briefly describe the research approach.

The fourth chapter reflects observations made by the Lighthouse project SMART-RAIL in terms of competitiveness considering the specific costs of road and rail transport. These are complemented by recent EUROSTAT publications. Furthermore, research results from SPECTRUM on transport trends and recent investigations of S2R cross-cutting activities on customer needs were reflected.

The comparison leads to the conclusion that the low competitiveness of rail freight today is not due to the cost position, but due to other criteria.

Chapters 5 and 6 present the various solutions and technologies that are developed within the framework of the various IP5 projects and describes the respective innovation potential and the objective of a solution or technology. It is also to show possible benefits expected by the experts. Section 6 also describes the form in which the solutions pay into the three main KPIs of Shift2Rail (LCC, punctuality and capacity) and which stakeholders would benefit significantly from the market launch.

While in Chapter 6 the effects and benefits are considered essentially without compound effect, Chapter 7 deals with the first research results of the CCA project IMPACT-2, that with its models evaluates positive as well as negative effects of the solutions in interaction with each other.

Chapters 8 to 10 are then devoted to migration considerations in more detail. In addition to important general information on the migration of new technologies with different degrees of novelty (Chapter 8) there is also a section in this chapter which highlights the financial aspects of migration, the presumably cautious willingness to make new investments with only a slight increase in productivity. The ninth chapter sets out a rough timeline as to when which technologies will be ready for the market. The perspective of the transformation of the sector is discussed with scenarios. Chapter 10 presents reasonable initial steps to start the migration process with reasonable measures for market uptake.

2 Background and Objectives

Generally, it is the aim of all measures in IP5 to make not only reasonable but also ambitious contributions to the S2R goals. Due to economic and logistical reasons, newly developed solutions can't be implemented at once. In some cases, technologies and/or solutions developed in IP5 depend on another. That means, the innovation measures must be put in a logical and chronological order to ensure a successful market uptake. Therefore, innovation graphs/paths are projected in an interdependence table from which the migration plan for European freight rail, market segments and stakeholders can be derived. The migration plan will have a great effect on the innovation capacity by proving that a better order of technology implementation will lead to fasters benefits for the customers.

The migration plan is going to show ways how to introduce new technologies under market conditions by clearly describing benefits and availability of solutions for shippers, operators and customers, taking dependencies between technologies and solutions, their evolutionary steps into account. It is a compilation of relevant technology and innovation paths for European freight rail. The focus lies on a joint perspective of users and solution providers describing benefits of key technologies carried out not only in FR8HUB but also in the other projects of IP5.

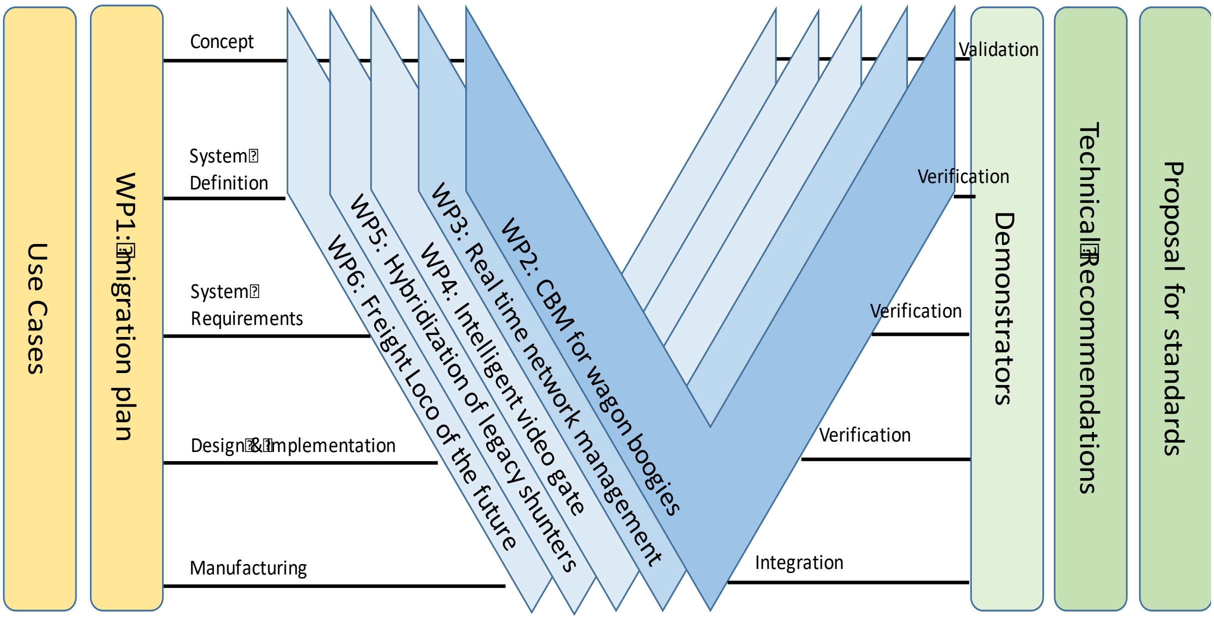

Figure 1. V-model

The migration plan is also following the V-model approach but as a general guidance for integration of different techniques, technologies and objectives in the whole of IP5 and has thereby a larger scope than applicable in the diagram above.

The work of WP1 is carried out in three phases

1. Identification of key technologies that are carried out in the different TDs and connections between them (incl. results of SMART-RAIL)
2. Creation of a logical timeline along the different functional levels of each key technology/solution
3. Evaluation of benefits to shippers, customers and operators (incl. short-term wins)

The compilation of the three phases will lead to the overall migration plan and is expected to be a consistent and realistic concept for the market introduction and European wide roll-out of the different technologies and solutions developed in IP5.

The work break-down structure was set as follows:

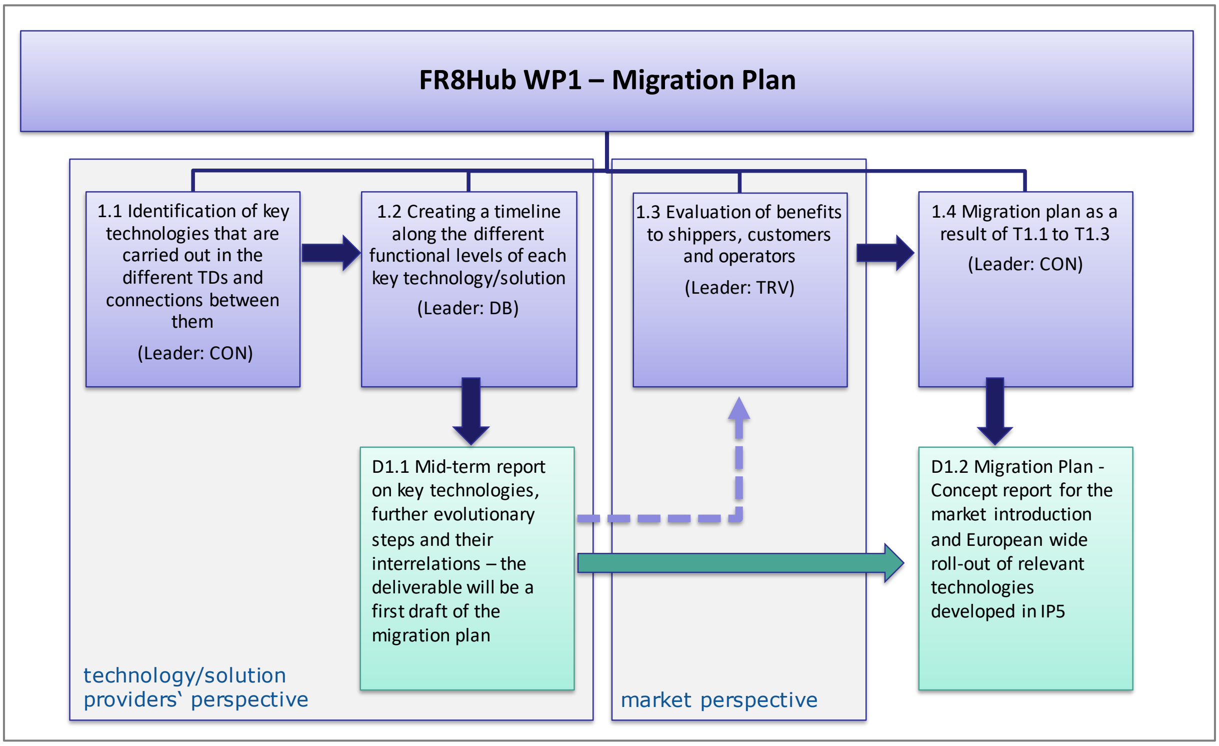

Figure 2. Work break-down structure of WP1

3 Investigation Approach

The study design follows the TD structure in IP5 and illuminates the technologies and solutions developed therein. First, the results of all work packages of the current projects (FFL4E, ARCC, FR8RAIL and FR8HUB) were examined. In part, it was necessary to fall back on the information in the individual project proposals. Furthermore, the experts of the TDs were approached to describe the future development steps planned for the upcoming projects in IP5.

In order to develop a migration strategy, it is fundamentally important to describe the status quo of the sector and to develop a common understanding of it without blinkers in the sector. For this study, the results of business analytics (TD5.5) from FR8RAIL were used, early study results from SMART-RAIL, SPECTRUM were consulted and a close exchange with the activities in CCA was sought. Further analyses and modelling were carried out on this basis.

The results and first migration approaches were discussed in a one-and-a-half-day workshop at the end of February 2020 with numerous experts from RU, IM, industry, science and politics. In addition to the current and future competitive situation (to the road), the impact of various solution levers and the results of the KPI assessment known to date were also discussed. The second day was used intensively for the presentation and discussion of the two-part migration approach of evolution and revolution. The findings and opinions of the workshop have been incorporated into the present document at various points.

As described above, the identification of the relevant technologies and solutions follows the TD structure of IP5. As can be seen from the graph below, the technology and solution-oriented TDs are relevant for the analysis. These are TD5.1 to TD5.4 and are examined in more detail.

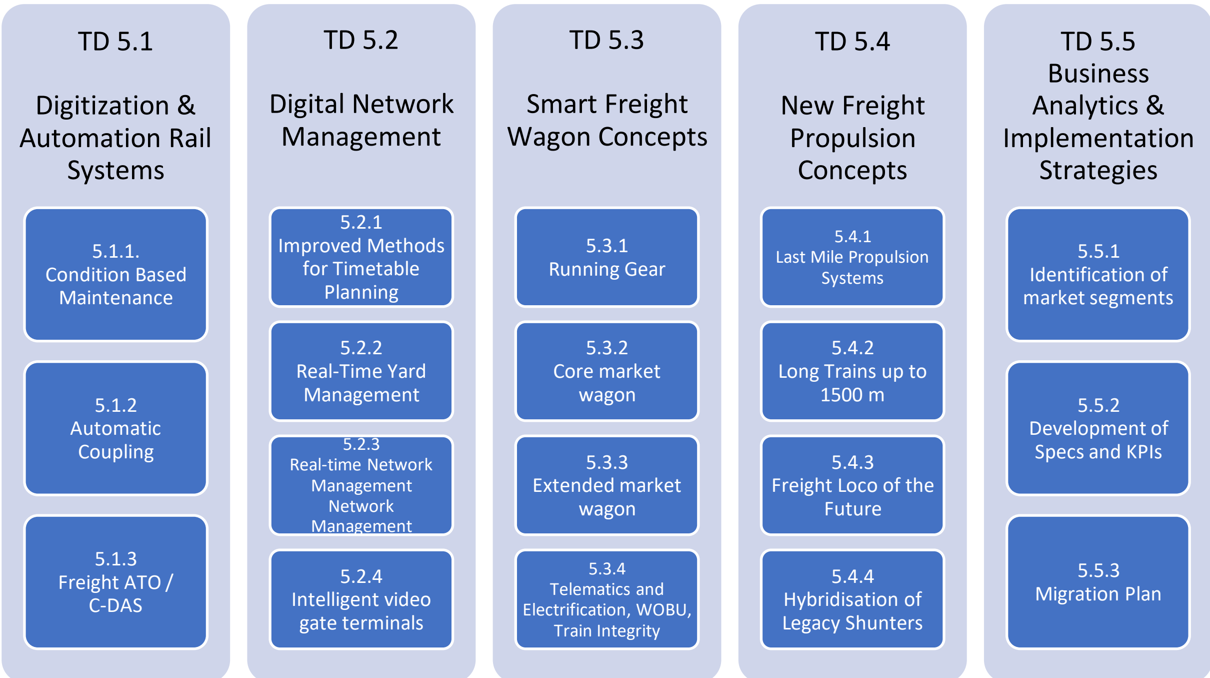

Figure 3. TD structure of IP5

4 Operations and Competitiveness in Transport Business

This chapter mainly deals with the current state of the railways - not only in terms of costs but also the services offered by the sector as a whole. It outlines some trends in the transport sector and customers' requirements or expectations of rail freight. Since the additional market shares must be taken from the road, the importance of LDHV goods is described and comparisons are also made with road freight logistics where appropriate. Research results from previous projects (also outside Shift2Rail) will also be used.

4.1 SMART-RAIL Recognitions and Recommendations

The Light House project SMART-RAIL did recommend to Shift2Rail IP5 not focussing so much on improvements on the market segments which are successfully served today by rail, because in this segments rail is obviously competitive under cost considerations.

Indeed, the calculations of the average costs of transport per tonne-km show that the cost of rail production (4 to 5 ct/tkm) is significantly lower than the one on road (Figure 4). The recent calculations within Shift2Rail project Impact-2 confirms this recognition when presenting even lower values between 3 and 4 ct/tkm.

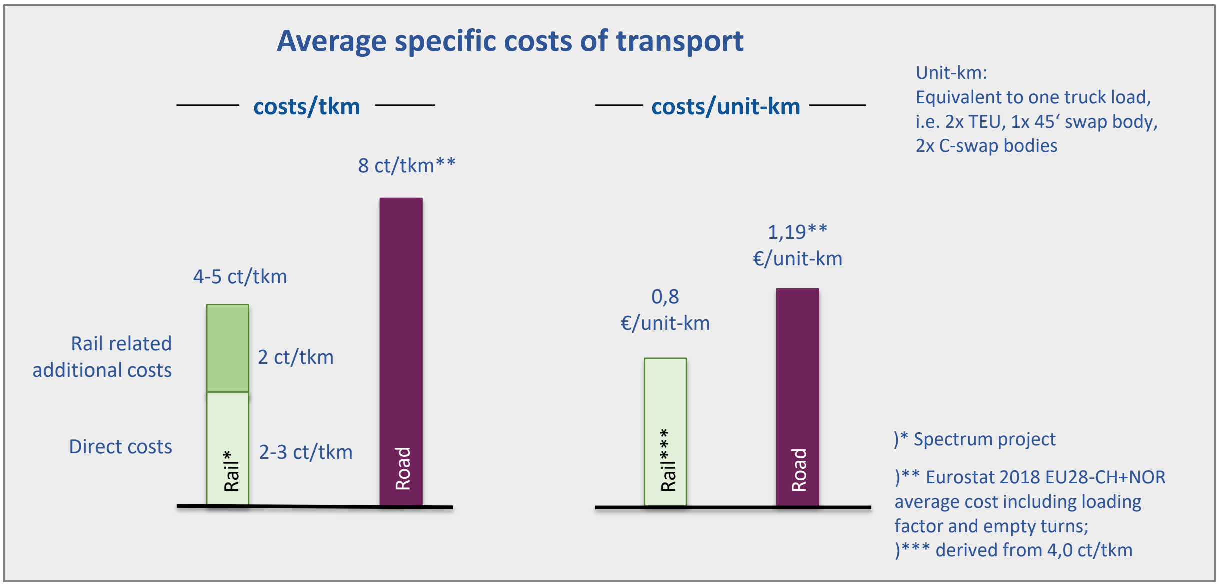

Figure 4. Specific costs of land-based transport

SMART-RAIL deducted from this fact, that beside cost there must be other severe disadvantages in rail offering to the transport market so that most of the market segments became dominated by road. Summarized in findings on the weak competitiveness of the freight rail sector the outcome of SMART-RAIL can be described as follows:

- **Mind-set of the rail sector**: Focus on timetable and train operations instead of supply chain orientation.
- **Transparency**: No digital workflow from end-to-end. Shippers and Forwarders and their customer do not get the right status of the transport in time.
- **Efficiency**: direct rail transport costs only +/- 50% of total rail related Supply Chain Costs (Shunting, transfer to marshalling yards, train set-up, complexity costs, waiting time)

- **Innovation**: Rail sector is captured in mutual dependencies between the various involved companies and stakeholders. The status quo is very hardly to change.
- **Flexibility**: The adaptability of the production system to incidents in operation is not part of its design.

Among these enumerations, the cost efficiency is only one point out of five and 40 to 50 % of the total cost are related to additional cost caused by the rail production process and not by the transport itself. SMART-RAIL recommendation is therefore to put the emphasis on improving the total offering to the transport market to gain market share in the road domains. This should be achieved by focussing on:

- Reducing complexity of the production process
- Changing mind-set from Rail operator so service provider with strong cooperation vertical and horizontal in the transport sector and
- Digitalization of the production process and integrating them in the overall supply chain of the logistic markets.

The cost position of rail had been controversially discussed with stakeholders in the WP1's workshop on migration plan activities in February 20202 as the presented facts do not fit to the common perception on the reasons for the lack of competitiveness of rail. A cross check on the published annual reports gave strong evidence that the calculation from SPECTRUM have been correct. The following tables shows turnover plus losses divided by the traffic performance for DB Cargo and Green Cargo. The values are within the range of the calculation from SPECTRUM (see table

Table 1: Comparison of turnover per tkm at DB Cargo and Green Cargo as evidence of low competitiveness of rail freight services

DB Cargo 2018		
Turnover (total)	4.460.000.000	Euro
Loss	190.000.000	Euro
Transport performance	88.237.000.000	tkm
Turnover per tkm	**5,055**	**€ct/tkm**

Green Cargo 2017		
Turnover (total)	4.300.000.000	SEK
Loss	122.000.000	Euro
exchange rate SEK/€	0,10	
Transport performance	11.800.000.000	tkm
Turnover per tkm	**3,644**	**€ct/tkm**

That means, that the rail sector must totally re-invent its production systems to really become competitive with the road. It is not promising to focus on efficiency when the freight rail sector is not able to turn the better cost position in success in the transport market today. Shorter lead time, reliable prediction, transparancy and better responsiveness to the customer needs must be the imperative.

The investigations within FR8Hub confirm this view on the current status of rail freight transport. The migration plan must put therefore strong attention to improving the competitiveness in the market which are currently dominated by road. Nonetheless, looking one decade ahead the possibilities in improving the market position in the core markets of freight rail should not be lost in perspective, because the cost reduction of road transport when changing to autonomous operation and platooning can be up to 50 %. The road average cost of transport will then be in the range of the rail freight transport today, which could cause further down take of the modal share for rail.

4.2 SPECTRUM Project and the Relevance of LDHV Goods

SPECTRUM (project acronym for Solutions and Processes to Enhance the Competitiveness of Transport by Rail in Unexploited Markets) has explored the market opportunities for transport of low density, high value (LDHV) goods, utilising new and innovative rail concepts. Focus was on the extension of existing 21st century rail services **and more visionary rail logistics services**. Its research was built upon with an assessment of existing conceptual designs and a shift in focus to assess technical and operational requirements.

The project (duration 2011 to 2015) developed a detailed design concept for a high-performance freight train that is lightweight, has running performance characteristics that allow mixed operation with passenger services, and is capable of accommodating the required types of freight container units. The design work included:

- Optimised, lightweight, energy-efficient freight wagon structures
- **High-speed running gear, including brakes and vehicle dynamics**
- Electrical systems and coupling arrangements
- The **handling of freight container units**

The following remarks take up parts of the market investigations at that time and summarise the essential findings In addition to market trends and logistical requirements, the importance of containerised transports and the so-called LDHV goods (see FR8RAIL deliverable D1.1 for further explanation and definition) is addressed in particular.

4.2.1 General Market Trends

One of the trends identified by SPECTRUM **was a possible (partial) reversal of globalised flows of goods through in-shoring/in-sourcing**. Focusing on the member states of the European Union, some industries have already completely moved outside the EU (e.g. manufacturing of shoes, textiles), whereas the location structure of others can be characterised by global production networks with an intense internal exchange of components and semi-finished products (e.g. automotive or chemical industry).

Today, due to a couple of known effects (e.g. higher energy prices and labour costs) going hand in hand with globalization, for some of the goods, the trend might be reversed, so that there would be in-sourcing/in-shoring instead of outsourcing/off-shoring (i.e. reverse sourcing of manufacturing and production activities). The current Corona pandemic underlines the importance of national manufacturing and production capacities and leads to a public debate about the limits of globalisation and a partly demanded return to national production activities.

Such a reversal will have an impact on the origins/destinations of the flows of goods or on the logistical parameters. Among other factors In-shoring may include:

- **Lower logistical risks**
- **Shorter delivery times** to domestic clients
- **Quality issues**
- **Improved time-to-react (flexibility)**

- More chances to establish a quality management across the supply chain
- Improved intra-company communication (language, culture, media)
- Legal certainty[1]

SPECTRUM further points to the increasing congestion of Europe's transport infrastructure when it comes to backshifting of production activities. In the longer term, road and rail infrastructure with current methods, systems and business models might not easily be able to cope with the increase in freight traffic, which is already the case especially around conurbations of European metropolises and along some European transport corridors.

Supply and production networks would have to adapt to the capacity of the infrastructure or use alternative modes of transport. This would mean regional supply and production networks consisting of a larger number of less specialised production sites supplied by local suppliers and serving local customers

Such a scenario would have different impacts on the transport economy: There would be more continental and less intercontinental freight, which would undoubtedly lead to a lower volume of air and sea freight. **In addition, average transport distances would decrease and there would be more regional freight transport. Customers would become accustomed to shorter turnaround/lead times.** If rail freight services are to participate in the growth of such segments of the freight market,

- they must offer fast and frequent connections that are economical over short distances (even when transporting smaller freight volumes),
- and they must operate on rail networks with a large number of regional access points.

In other words, time accessibility and spatial accessibility of the services (accessibility to the overall system) should be high. It has long been known and is still pervasive today that trends in infrastructure show the opposite of this requirement, with the elimination of sidings, terminals, tracks and lines and the concentration of functions in larger but fewer facilities.

The overwrought and manifest focus on cost cutting and the elimination of lines and sidings over several decades across Europe is now effectively excluding rail from certain markets unless significant investment in infrastructure is made and different technical, commercial and new operational models are used to restore capacity and performance.

Products, orders and deliveries & City logistics.
The following four points are pertinent:

1. more product customisation;
2. toward increasingly compact products (this is expected to improve the cost-benefit ratio of express delivery by decreasing the transportation cost share);
3. the increasing value of products requires rapid transportation, because companies want to reduce the interest costs bound up in stock and inventories;
4. more varied, frequent, faster and more reliable deliveries; more focus on service quality rather than on delivery price.

Again, the extra value that is created may accrue to the HV segment. Rapid transportation may create possibilities for transport by rail, given an area where this has a comparative advantage above road transport. Such areas may exist, where for example it is easier for trains to penetrate and operate in urban areas or where certain inter-urban roads are heavily congested. **The increasing urbanisation of the population raises the importance of city logistics concepts** such as freight

[1] Spectrum, D1.3, p. 27/28

consolidation schemes and the interfaces with long-distance transport networks and services. Benefits can only be realised with the existence of efficient connections between rail networks and urban transport networks.[2]

4.2.2 Transport Trends

SPECTRUM also describes the **change in freight characteristics and cargo properties**. Throughout the last decades, in Europe, there have been changes in the characteristics of freight. These changes had an effect on transport and logistics. Resulting from the socio-economic development, a shift can be observed: There is less bulk to be carried, and more general cargo. In more detail, as the steel industry, the primary industry, and the building industry have lost a notable part of its importance, so the total transport volume consists of less coal, ore and petroleum products and fewer minerals. For example in Germany, between 1998 and 2007, the share of these goods in total inland transport volume continuously diminished from almost 63 % to less than 51%.

Because of their low value, these bulk goods are sensitive to high transport costs, so they require low cost transport. Also, bulk is usually transported in large volumes, as larger volumes are ordered. It has lower demands on transport service quality (speed, punctuality), because the supply and demand flow to/from the industrial facilities is continuous and capital costs of the load play a minor role. Taking into account the features of the transport modes, this leads to a high affinity to railway (and inland waterway) transport, which has its strengths in the cost-efficient carriage of larger volumes. These transports offer a wholly different logistical performance than those being mostly covered by road transport.[3]

General cargo has a lower density (expressed in kg/m3) and a higher value (expressed in €/kg). Due to the latter, it is less sensitive to transport costs than bulk. Because of the high capital costs of the cargo, it requires a faster and much more time-definite delivery. The impact of capital costs dominates the impact of transport costs, which leads to a choice of fast and expensive transport options (e.g. air cargo). In addition, shippers and consignees usually request flexibility in transport planning and execution. As a trend for the transport industry, SPECTRUM points out that the cargo consists more and more of smaller and lighter goods. Instead of full truckloads, smaller lot sizes of general cargo need less-than-truckload transport services. Today, these consignments are mostly transported in groupage, pallet or parcel networks using consolidation hubs. The changed goods structure has a much higher affinity with trucks, which offer smaller capacities, a faster delivery, and a more flexible deployment.[4]

With regard to infrastructure, SPECTRUM, as well as the studies in FR8RAIL (D1.2 Top Level Requirements), points to the **need to integrate rail freight with faster and more dynamic passenger transport**. Especially within Europe the densely used networks for mixed traffic face operational problems resulting from the different characteristics of passenger and freight transport (e.g. speed, acceleration and braking). The requirements of passenger and freight transport on the railway infrastructure are very different. On less heavily used lines, the common use of passenger and freight trains is normally not a big problem, but on heavily used main lines this can pose problems. The main problem is the different speeds of (generally faster) long distance passenger trains and freight trains, but also the different stopping patterns of regional trains calling all/many stations. It would be preferable for long distance freight trains to have no intermediate stops or be queuing as a result of interaction with regional or stopping passenger services. In most cases freight trains have to wait while passenger trains are passing. Another problem is that freight trains need more flexible

[2] Spectrum, D1.3, p. 29
[3] Spectrum, D1.1, p. 16
[4] Spectrum, D1.1, p. 17

timetables, because the actual departure of a freight train depends on many variables, e.g. the need of the shipper, the loading process and necessary waiting times because of passing passenger trains. Whereas passenger trains have a fixed timetable and should stick to it, in order to make the customer an attractive offer. Generally, the ideal solution for these problems would be the effective separation of passenger and freight on different lines. This is often not possible. In these cases, a more flexible operation is often required. For freight trains there could be several freight priority slots distributed over the day. These slots can be used flexibly for freight trains if necessary. With this solution the differing requirements of passenger and freight trains can best be accommodated.[5]

4.2.3 The Importance of Containerised Cargo/Loading Units for Rail Freight Transport.

The global market is witnessing a growing relevance of the container as the preferred loading unit. The ability to move trailer-sized loads seamlessly between different modes of transport has revolutionised the international flow of goods to a remarkable extent by consistently reducing transport costs:

- Door-to-door transport: the average time in port decreased from 3 weeks (pre-container scenario) to 18 hours or less.
- Labour costs: the productivity grew from 0.627 tons per man-hour (pre-container scenario) to 4234 tons per man-hour.
- Cargo loss and damage.[6]

Essentially the container made shipping and the following inland leg of transport much faster and cheaper. At a global scale, the annual rate of growth of containerised trade has been equal to 12% in the 2001-2005 time-frame and is estimated to be 6.5 % per year until the end of 2011. The share of goods carried by containers is around 80 % in the developed countries and around 30% in developing countries, suggesting that a continuous diffusion of this type of loading unit will continue to take place.

SPECTRUM was right: A look at current figures shows that the development of global loading capacities has increased constantly despite interim overcapacities and the associated consolidation among shipping companies (see Figure 5).

[5] SPESTRUM, D1.3, p. 37
[6] SPECTRUM, D1.3, p. 31

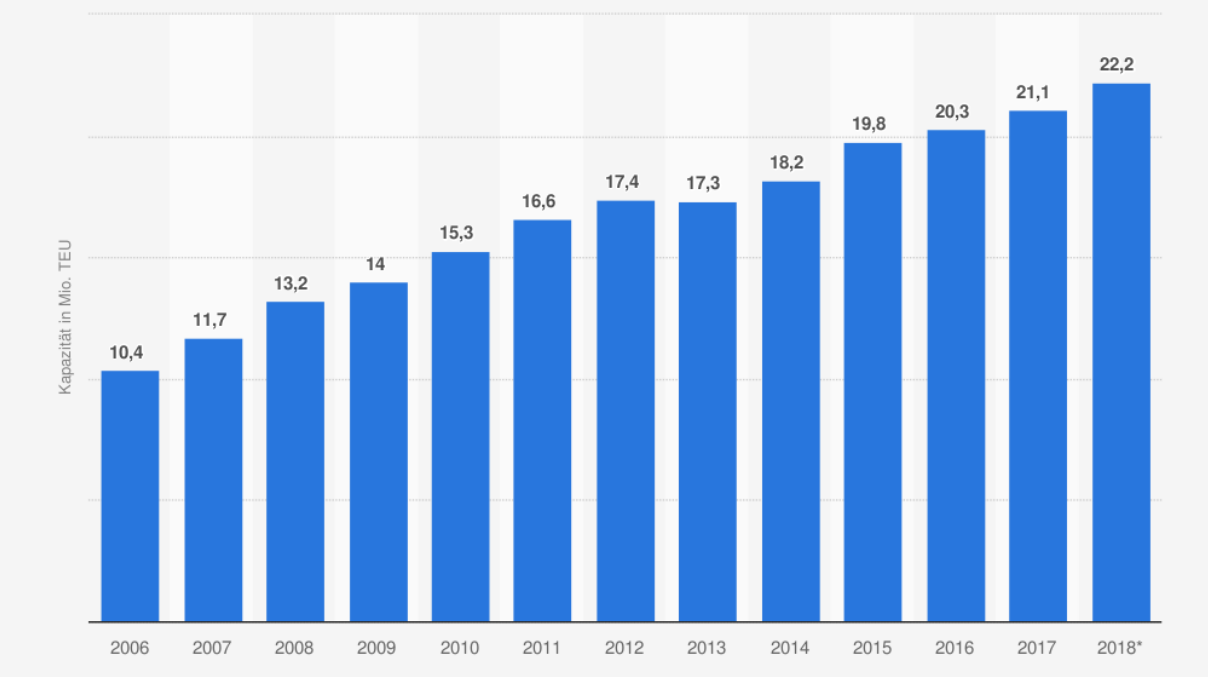

Figure 5. Capacity of the global container ship fleet in the years 2006 to 2018[7]

Furthermore, increased use of optimised loading units such as hi-cube containers and low-axle vehicles (which increase space of vehicles inside the weight limit of vehicle type) and the use of longer and heavier vehicles have an impact on the transport market and can provide benefits for intermodal transport.

Rail has not always been ready to recognise or respond these changes leading to a loss of market share. Road transport has been much more adaptable and pro-active in the development of new technical and commercial offers as shippers' requirements have emerged and evolved (see also chapter 8.6 Sector Organisation and Solidification).

The preceding presentations from Spectrum, current figures as well as the market analysis in FR8RAIL on the market segments and the potential derived from them underline the enormous importance of containers/interchangeable loading units - also for gaining market share on the railways. Containerised goods and LDHV goods are target segments to which the IP5 has also committed itself with the advanced and future-oriented wagon concept of the Extended Market Wagon (EMW), because these are dominated by truck-based. Only here will it be possible to gain the market shares desired and demanded by the EU.

4.3 Freight Customer Needs – Findings of S2R CCA

The main goal of Shift2Rail is to develop technologies and promote innovations that not only improve the rail system, but also make it much more attractive to attract more passengers and transport more goods compared to other modes of transport. And for this, it is important to know the needs of the customers. Previous research projects have dealt with this (see previously cited studies or projects). However, in order to identify potential for improvement and to derive requirements, it is also necessary to mirror the current perception of the sector. This is exactly what

[7] Statista.de based on data of Clarkson Research Services; MDS Transmodal; Ernst Russ; Norddeutsche Landesbank, 2021

a study of cross-cutting activities has done for IP5, i.e. rail freight transport, and has developed criteria that have been assessed by customers with regard to current performance (sector perception) and today's and future importance. To address both wagon technologies CMW and EMW, rail affine customers and others that mainly transport LDHV goods were asked.

The figure below shows the point ratings for various criteria relevant to the transport decision. The columns represent the importance or significance of the criteria for the decision to transport by rail. The grey columns represent today's importance and the light green columns above them reflect the future importance. It can thus be stated that all criteria are gaining in importance for future transport decisions. In other words, customers are once again raising the bar for the performance of rail when they consider transport by rail.

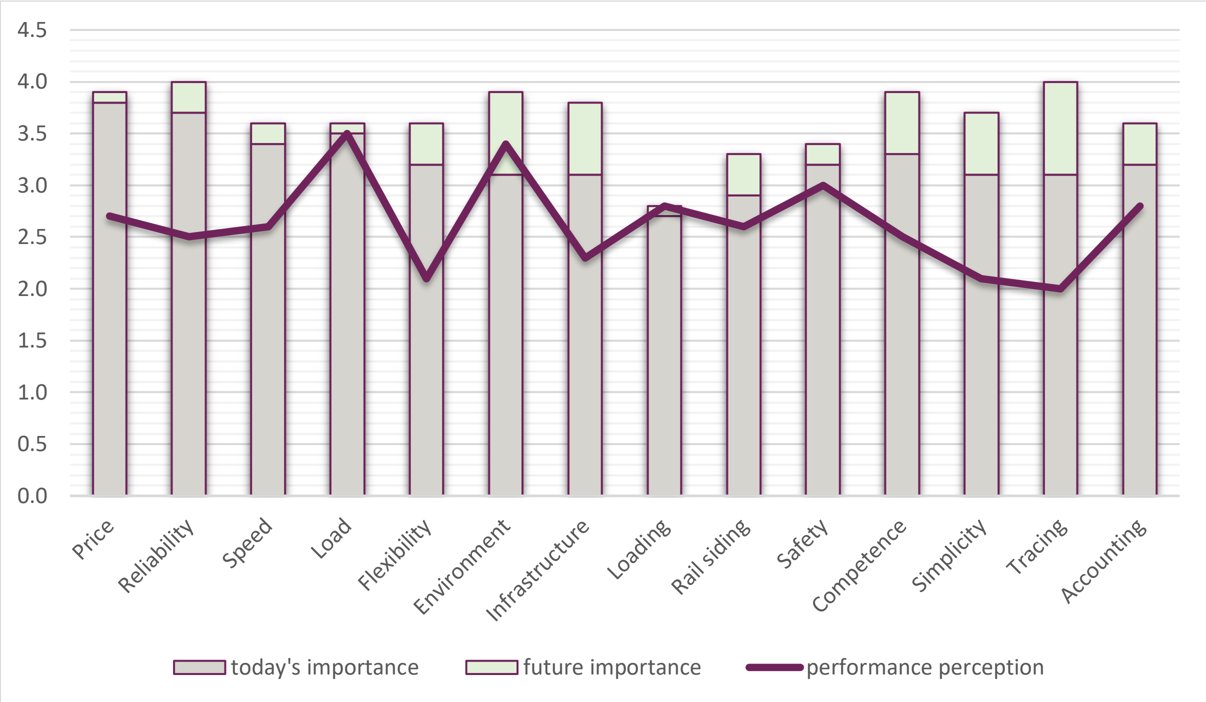

Figure 6. CCA investigation on freight customer needs

The purple line represents the current state, i.e. how customers assess the performance of rail-based transport today. It is confirmed that rail does not meet expectations in the majority of criteria. The gaps between actual and target are particularly large and thus can be interpreted as the degree of underperformance for:

- reliability,
- flexibility,
- infrastructure,
- simplicity and
- traceability.

This again confirms similar studies on customer needs from earlier studies and projects (partly from the early 2000s). The current results further illustrate that apparently the last decade was also not or only insufficiently used to address these open points in competition with the road.

Likewise, two other criteria stand out where the deviation is similarly large: price and speed.

As was pointed out in chapter 4.1, the specific costs of transport are lower on rail than on road. However, in CCA's research, the price does not seem to meet the customers' expectation - it is obviously perceived as too high. One explanation may be that the rail network is less dense than the road network, making it inevitable to travel a longer distance by rail for the same transport task than by road; with the consequence that price and speed or transport time increase to the disadvantage of rail. In addition to the less dense rail network, the location and number of access points (terminals, sidings) are also important for the transport distance by rail.

The distance efficiency seems to be lower than on the road. In the end, the cost advantages related to the specific costs cannot be used to the advantage of rail. The parameter "distance efficiency" and its possibly underestimated importance will be discussed in more detail in the sensitivity analyses in chapter 7.2.

However, it should be noted here that with the price, a criterion that directly affects the transport decision in favour of rail or against rail is not used for competitive advantage. As CCA correctly assesses in our opinion, the "direct criteria" are influenced by both technology and processes. Against the background of poorer distance efficiency, it is therefore necessary to develop alternatives to today's established production concepts (see following chapter 4.4).

4.4 Future Production Modes for a competitive Rail Freight System

When addressing a shift of road freight transport to rail the absolute driver for any progress in the rail systems will be to fulfil the needs of the shippers and its customers, which have been preferring road transport for decades. This implies a critical view of freight train operations to assure that the future wagon design will fit to operational modes that really could compete with the road transport.

To make the production process on rail as productive as possible the focus should be on block train operations in the future according to the results of the FR8RAIL Market investigation[8]:

- either in Point-to-Point mode (P2P-train) as it is used today for factory to factory transports with large quantities of goods or in the “Hafenhinterland”-traffic (Figure 7) or

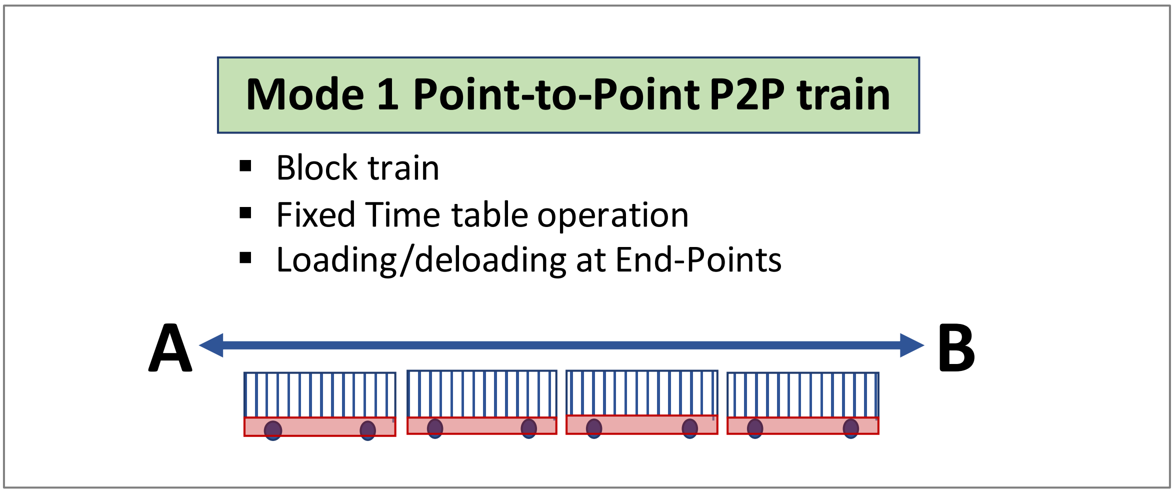

Figure 7. Operational mode 1 - Point-to-Point (P2P)

[8] FR8RAIL D1.2 Top level requirements, development of technical specifications for wagon application, p. 8-10

- with a Closed Train Loop on a timetable basis to attract container and swap body transports to the rail system at terminals where the loading and de-loading are operated.

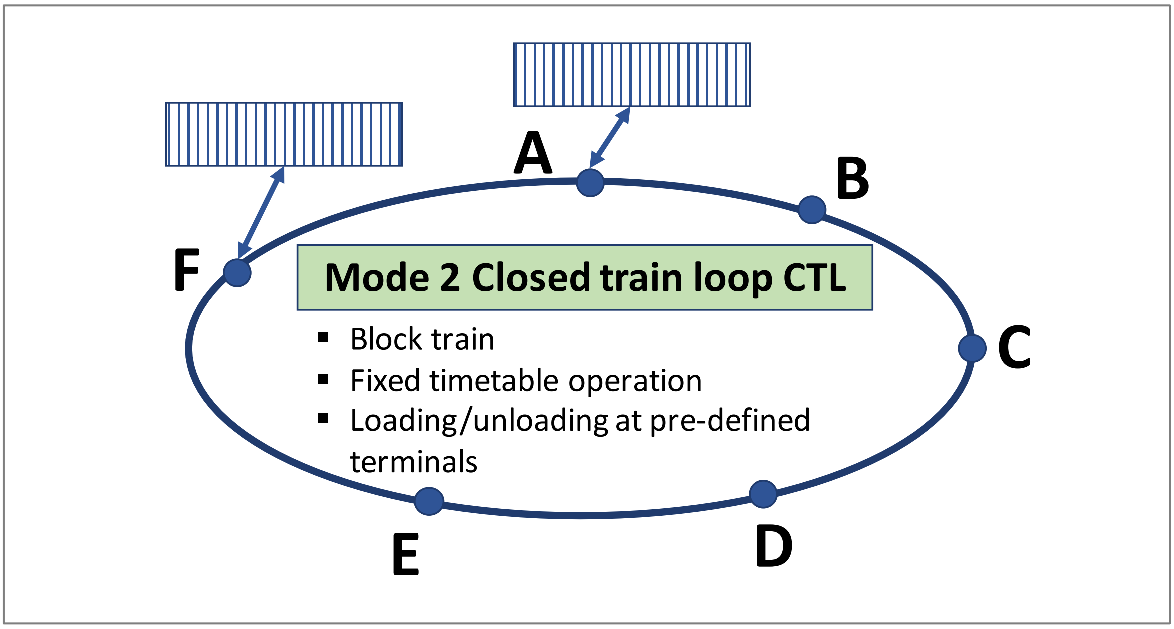

Figure 8. Operational mode 2 - Closed Train Loop (CTL)

Block train operation in this sense is defined as a mode in which the train set will remain unchanged for a long period of time. Disassembling should only occur in case of repair and overhauling work not as part of the operational process itself. The advantage of the block train is obviously that any cost and time-consuming processes for the train formation will be eliminated.

The single wagon load business which is often discussed in the railway industry is not competitive against the road offerings as the process of production with feeding, re-formation of trains and de-assembling and distribution to the final destination is too ineffective and too expensive. To relaunch SWL to the transport market successfully and to re-enter the groupage business it is necessary to streamline the production process on rail and link it to the transport modes on road. Therefore, this type of business should be organised on a timetable basis and allow decentralised train formation where the transport market is asking for it and not where marshalling yards seems to be well positioned from a rail network point of view. This means that the train and respectively the wagon must be able for an atomized and autonomous train formation in small stations with a minimum number of tracks, switches and crossings. Obviously, the intelligence must be transferred partly from the infrastructure to the train itself.

The operational mode can be described as an Open Train Loop OTL as the train follows a fixed schedule but changes the formation partly at every planned stop.

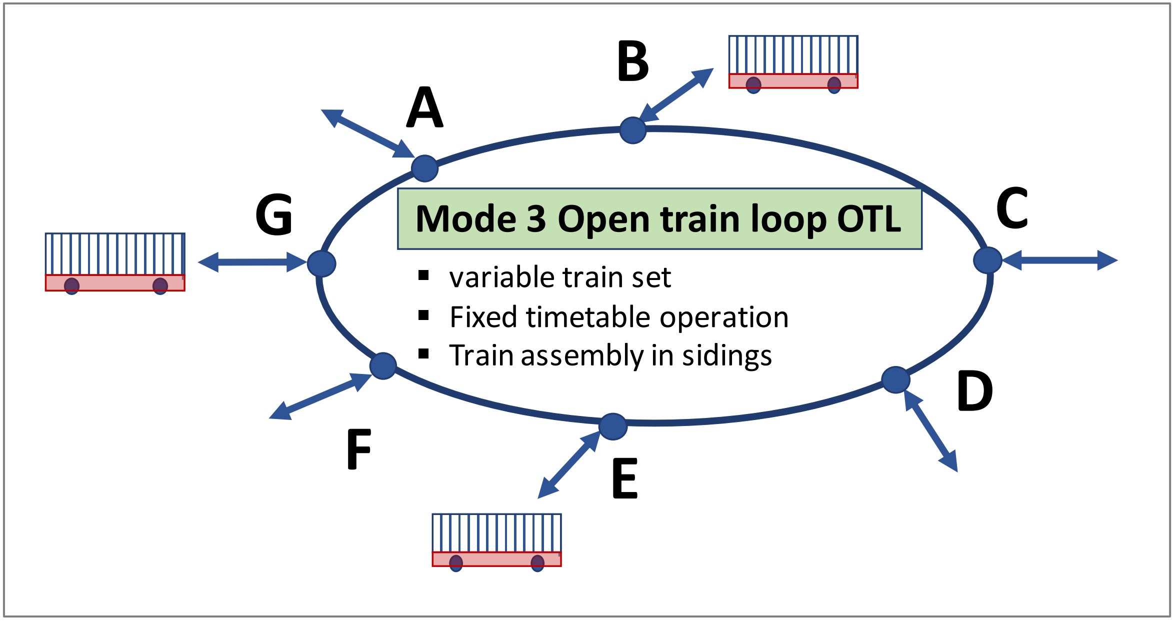

Figure 9. Operational mode 3 - Open Train Loop (OTL)

In the migration phase the wagons for OTL operations can be used in the marshalling yard as well - with some restrictions which will be discussed in the following chapters.[9]

The production modes presented here lead to significantly higher productivity in terms of the use of production resources and reduce or eliminate complex and costly processes on the infrastructure side.[10] Furthermore, they significantly reduce the specific personnel requirements for rail freight transport, because all three production processes are designed to keep the freight train moving as much as possible, i.e. the share of pure transport time increases. Therefore, for example, not only the number of vehicles required decreases significantly, but also the need for operating staff.

[9] FR8RAIL D1.2 Top level requirements, p. 8-10
[10] FR8RAIL D1.2 Top level requirements, p. 10

5 Identification of Key Technologies – Description of identified Solutions

5.1 Digitization & Automation Rail Systems (TD 5.1)

5.1.1 Condition Based Maintenance

Maintenance related expenses are one of the largest contributors to the LCC of the railway system. For example, DB Netz in 2012 estimated the maintenance costs to be over 50 % of the LCC, without the effect of unavailability. On the other hand, in dense traffic lines the availability of the lines is the key parameter that monitors the maintenance schedules. The cost of unavailability and the penalties that maintenance service providers suffer are huge and impact directly in the profitability of the companies.

Consequently, maintenance service providers of train operating companies are very concerned optimizing on one hand the cost of maintenance services and on the other the risks associated to the operation. The FR8HUB consortium will develop technologies and processes part of the overall CBM strategy that will optimize cost while maintaining the safe operation. The technologies developed in the area of CBM are expected to reduce the maintenance cost in a range of 10 %. This will contribute to reduce the operational costs of rail freight transportation.

Condition based and predictive maintenance will achieve a paradigm shift from costly predetermined to cost efficient condition based and predictive maintenance due to monitoring the component status.[11]

Innovation Potential FR8RAIL1

Condition based maintenance will change completely the organizational model of maintenance services where maintenance units traditionally work like a production chain reducing the number of human resources at expenses of the availability of the asset. Condition based maintenance will provoke a change of paradigm in maintenance process and will evolve to a situation where the information about the asset is the driving force and all the operations are focused on reducing asset unavailability.[12]

Innovation Potential FR8HUB

At the end of Shift2Rail the ambition related to the Condition Based Maintenance (CBM) strategy is to reach TRL 7. Savings will result both through the avoidance of services pre-determined by long standing maintenance guidelines and through the significantly improved reliability of rolling stock meaning more productive hours. CBM will result in more and more accurate forecasts overtime, as the amount of data from the component monitoring becomes big data which at the end turns to smart data, to be processed into advanced status warnings and allocated to the ideal maintenance shops. Beyond the intelligence of system functions i.e. recognition of patterns and neural prognostics, the core innovation of CBM takes place at the process level.[13]

[11] FR8RAIL proposal, p. 19
[12] FR8RAIL proposal, p. 17
[13] FR8HUB proposal, p. 22

Objectives FR8RAIL

The condition based and predictive maintenance project focuses in the first stage on:

- Develop an overall condition based and predictive maintenance strategy for rail freight rolling stock (locomotives and wagons) in alignment with all overall Shift2Rail targets.
- Definition of new roles (e.g. reliability engineering) and responsibilities (e.g. technical support) in the interaction of the area asset, fleet and maintenance management.
- Develop a condition based and predictive maintenance program based on specific locomotives and based on several components

At a later stage of Shift2Rail (in successive projects) it is foreseen to combine the experiences, lessons learned and the basis which will be set by WP 3-Telematics and electrification for freight wagons (electrification, on-board-units and wagon monitoring system) and the CBM experience from locomotives to include freight wagons into the CBM strategy. In this first call the integration of the condition based and predictive maintenance strategy will mainly focus on locomotives and the basis for wagon integration will be set.[14]

Objectives FR8HUB

Wheel flatness, ovalisation and poligonisation, degradation of suspension, and degradation of bearings are considered the most critical failures, which trigger wagon maintenance. State of the art technology can capture physical variables to monitor their performance.

However, there are not cost-effective solutions connected with reference values capable of providing recommendation and alarms to trigger maintenance actions. One of the bottlenecks is the development of algorithms adapted to specific sensors and the integration of the data within a maintenance information system. Therefore, research in three areas was proposed:

- Specification of sensors selected for the monitoring of physical parameters, which will early inform about most typical failures of wagon components and development of ad-hoc algorithms for identification of health status and degradation trends.
- Laboratory tests to acquire data of the failure of the wagon components to be monitored.
- Synchronization of measured values in position in the vehicle and the route, and timing. This will allow the filtering of externally generated noise that might trigger false alarms, e.g. squats or rail corrugation might be perceived as a failure in the axle bearing.
- For a commercially attractive solution, it is required the use of wireless communication system with low power and low data rate, therefore the development of efficient pre-processing and compression of information it is necessary.
- A Field test campaign of the design covered in this WP will be carried out.[15]

5.1.2 Automatic Coupling

A general characteristic of the railway system is the joining of individual vehicles (mostly locomotives and wagons in the freight operation) to train sets. These vehicles are mechanically connected by use of mainly screw couplers to allow safe operation.

An Automatic Coupler (AC) is any type of coupler, which is not fully hand operated (manual). It is easy visible by the exclusion of e.g. screw couplers, link and pin couplers, hook couplers.[16]

[14] FR8RAIL proposal, page 33
[15] FR8HUB proposal, page 37
[16] FR8RAIL D5.1 - State of the Art on Automatic Couplers, page 9

The attempts to introduce automatic couplers (AC) are almost as old as the railways are. Several different designs have been developed over time. Resulting from the specific situation in Europe sometimes quite sophisticated types of AC have been designed, but due to the fractured structure of the European Railway system no general decision for an introduction in a wider scale was taken and executed.[17]

Different technical principles are possible and have been realized in the technical history and so are crucial to achieve the possible levels of automation:

Manual coupler - Coupling and uncoupling is done by hand: e.g. screw coupler or "link and pin" coupler. Operation when coupling: bring the buffers or couplers in contact, then fix and tighten the screw coupler or insert the pins into the coupling links.

Semi-automatic coupler - Coupling is executed automatically, when the vehicles are shunted in tight contact with a certain speed or force; this enables the latching mechanism to connect both couplers. But uncoupling is still triggered by hand, in most cases by removing parts of the latching mechanism with a handle. Also, manual coupling / uncoupling of the air pipe and electric connection for signals and power are specific for semi-automatic couplers. From that point of view all existing types of AC in freight operation are semi-automatic.

Automatic coupler - the coupling process here is almost the same as with the semi-automatic couplers: Automatic coupling, when wagons get in contact at a certain speed. Additionally, in this process also the connections of brake pipes and, if equipped with such devices, connections for signals and electricity are executed. Uncoupling, when needed, is remote controlled. No manual interference at the couplers is necessary.[18]

Table 2. Coupler types defined in the FR8RAIL project with different levels of automation and functionality[19]

Coupler type	Category	Description (automated functions)
Type 1	Manual	Mechanical coupling
Type 2	Semi	Type 1 + automatic coupling of air pipe
Type 3	Semi	Type 2 + automatic coupling of power and data bus line
Type 4	Semi	Type 3 + automatic de-coupling (manually actuated at wagon)
Type 5	Automatic	Type 3 + automatic de-coupling (remote-controlled)

Innovation Potential FR8RAIL1

Automated couplers will enable safer and more efficient terminal handling along with longer trains.

Innovation Potential FR8RAIL2

The automatic coupling will reduce operating costs in the vehicle composition and in the infrastructure. The infrastructure will be utilized more efficiently, operating longer trains at higher speeds. The new coupling will introduce additional features like the electric power connection in the wagons, enabling additional functionalities such as traceability, load monitoring and CBM.

[17] FR8RAIL D5.1 - State of the Art on Automatic Couplers, page 2
[18] FR8RAIL D5.1 - State of the Art on Automatic Couplers, page 9
[19] FR8RAIL D5.6 - Migration Plan for Automatic Couplers, page 15

5.1.3 Freight ATO / C-DAS

Communication between infrastructure managers and railway undertakings to manage the daily operations is most crucial for punctuality, capacity optimization and energy consumption. Today, only very few driver advisory systems on freight locomotives are connected to the IMs' Traffic Management Systems. Connected Driver Advisory Systems (C-DAS) will improve communication between IM and RU and reduce energy consumption by developing selected D-DAS functions.

The automation of activities today performed manually, such as for instance the train data entry for the start of mission under ETCS, the freight train brake tests or low speed shunting activities with more than one operator, will improve the overall operational efficiency. More important than the efficiency improvement itself, the automation of these activities is going to be key for the future ATO with grade of automation four (GoA4).

The International Association of Public Transport (UITP) Grades of Automation (GoA) system defines the degree of automation according to the level of responsibility assigned to the train control system. There are five grades:

GoA 0: manual operation with no automatic train protection
GoA 1: manual operation with automatic train protection
GoA 2: semi-automatic train operation (STO)
GoA 3: driverless train operation (DTO), and
GoA 4: unattended train operation (UTO).

Automated Brake Test
This analysis is followed by proposals for two solutions for automated brake testing, one for a partial automation, one for full automation of the brake test. In the first solution, partial automation, any extra equipment required onboard the rolling stock is concentrated to the locomotive and the provision of certain lineside equipment – i.e. no modification of wagons is needed. This solution aims at low implementation barriers and short introduction times, thus being able to deliver "quick wins" to the rail freight industry; it is partly based on innovative solutions to brake testing recently implemented in freight train operations in Canada.[20]

The second solution, full automation, eliminates entirely any manual interaction along the train. It reduces the time-consumption for brake testing even further and does not require any lineside equipment. At the same time, it requires in addition to an onboard unit on the locomotive the equipment of all wagons in a train with sensors, electric power for the sensors and data transmission, and either the use of automated couplers with an integrated data transmission cable or wireless data transmission to the locomotive; the system must have the capability to identify the order of wagons in a train. It requires also that certain other tasks, which are not part of the brake test as such, but which today are carried out in the context of the manual brake-testing procedures, can be automated. Thus, migration barriers for this solution are higher, while at the same time certain other innovations required for its implementation – such as a train-bus for data transmission along the train, electric power supply on the wagons and possibly automatic couplers – also deliver other important benefits beyond the automation of the brake test. [21] The brake test is then one function among others of an intelligent freight wagon.

Innovation Potential FR8RAIL1

[20] ARCC D1.3 - Automated Brake Test, page 2, 3
[21] ARCC D1.3 - Automated Brake Test, page 2, 3

Communication between IM and RU to manage the daily operations is most crucial for punctuality, capacity optimization and energy consumption. Today, only very few driver advisory systems on freight locomotives are connected to IMs traffic management systems. C-DAS will improve communication between IM and RU and reduce energy consumption by developing selected D-DAS functions.

5.2 Digital Network Management (TD 5.2)

Network management is the management of train activities on the line, and the impact on train operations that yard operations may have. The range of planning processes in railway operations today includes mainly timetable, infrastructure, vehicle scheduling, construction sites and crew management. There are also different planning horizons in which these processes can be considered.

The most general classification corresponds to the underlying railway operations management processes for strategic planning, tactical planning as well as operational traffic control and train driving. The planning processes within the scope of network management are short-term (daily timetable up to 1 year) and planning within the operational process, i.e. the ad-hoc planning process. For example, in Sweden, Trafikverket's planning department hands over the daily timetable to operational process at 3 p.m. the day before operation. The operational process, where the real-time traffic plan is updated, is also in scope.

5.2.1 Improved Methods for Timetable Planning

Basically, timetable planning can be divided into three main phases, the annual working timetable planning, the short term and ad hoc planning and last the planning during operations.

The **annual working timetable planning/long-term planning process** is often considered to start with the publication of the network statement (NS) one year in advance. The NS describes the preconditions for operating trains on the infrastructure. But from providing information on the physical tracks and planned large maintenance works, the NS also provides information on e.g. the allocation process, available services and charges. The entire planning process, which is mostly sequential and only partially digitally supported, can be represented as follows.

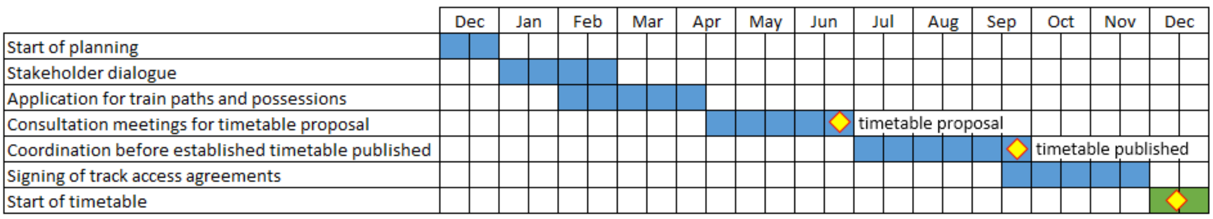

Figure 10. Example of the timetable planning process Trafikverket

The aim of the **short-term and ad hoc planning** is to make changes in the annual plans to accommodate new demand and traffic developments. The main output of the short-term and ad hoc planning are daily graphs, and detailed car bookings, personnel schedules and rolling-stock schedules to be used during operations. For the infrastructure manager, short-term and ad hoc planning comprises handling new applications for train paths and possessions, as well as changing the working timetable to cope with e.g. track breakage. For train operators the short-term planning comprises designing and applying for new train paths, or cancelling established train paths, depending on the business situation. However, during short term planning freight operator planners may also work with e.g. wagon re-booking in order to use the available train capacity in the best possible way.[22]

All the **planning work** stated above leads up to the **day of operation** when the transport services and maintenance works should be performed. The main task for operations staff is now to ensure that the train and maintenance works are delivered according to expectations. To their help, they have the planning output from previous process stages such as the daily graph and track usage plans, and a variety of information and communication tools. Apart from the operative production staff, such as locomotive drivers, dispatchers and maintenance technicians, there are also support staff, such as planners, customer service and managers who make high-level prioritisation decisions in case of disturbances. As the focus of this report is freight traffic, processes related to passenger information is omitted. Further, systems and processes related to maintenance and electric power are only superficially covered. Details of roles, responsibilities, tasks and processes can be found in ARC D2.2 - Description of business processes of a network management system and the interactions/interfaces with a Real-time Yard Management System.[23]

Rail freight traffic has other prerequisites than passenger traffic, both regarding planning and operations. Good timetable and operations planning processes should address both the needs of passenger traffic and freight traffic. Also, the freight transport planning and operation would benefit from an improved holistic perspective, in which the line planning is more integrated with the planning of the side system (i.e. marshalling yards and terminals).[24]

Comparing passenger rail traffic with freight rail traffic, it is common that the freight rail traffic has:

- Larger needs for planning of new trains within 2-3 months planning horizon.
- Larger needs for re-planning of trains (that are already included in the annual timetable) within 2-3 months planning horizon.
- Larger needs for flexibility.
- Larger flexibility.
- Need for changed departure times at short notice.
- More trains that run before their scheduled timetable slots.
- More trains that run significantly after their scheduled timetable slots.
- Other kind of punctuality needs and delay costs.
- Sometimes it is more important to be able to run a train than to do it efficiently and with high punctuality.
- The marshalling yards and terminals (“side system“) are more integrated in the transports from the dispatching customer to the receiving customer.
- Too often inefficient transports with unwanted waiting times along the line.
- Highly competitive market where efficiency is key to survival.

Based on these differences, potential targets may be identified for the development of the timetable process:

- The timetable planning process should be adapted to be able to handle the needs of both passenger and freight traffic.[25]
- The timetable planning process should acknowledge and utilize that freight and passenger traffic are different.
- Punctuality goals should be different for passenger and freight traffic.

[22] ARCC D2.2 - Description of business processes of a network management system and the interactions/interfaces with a Real-time Yard Management System, page 25

[23] ARCC D2.2, page 28

[24] ARCC D2.2, page 53

[25] ARCC D2.2, page 54

- The planning and capacity of the side systems should be more integrated into the planning of the railway lines.

Based on the above development needs, there are implications on how the timetabling processes and operational control could be enhanced in order to support the needs for freight traffic in general and in particular to support the coordination between line and yards/terminals:

- The capacity of the side system (yards/terminals) should be dimensioned according to actual traffic needs so that the capacities of these are not a limiting factor for the operations and development of the rail freight traffic.
- The information in the rail system should be transparent and shared whenever this creates common benefits and a more efficient overall railway system.
- The operational timetable should be updated daily to incorporate known disturbances, like temporary speed reductions or track maintenance.
- The operational timetable should be updated according to current and actual prerequisites for the (freight) trains, like actual train weight, maximum speed, acceleration profile, and braking characteristics.
- The nominal timetable should continuously be adjusted for systematic deviations, both regarding early and late trains.
- As soon as a RU expects a departure time deviation (delay or early departure) it should be communicated to the IM.
- Both RU and IM should make consequence aware decisions when planning a deviating departure time (compared to the nominal timetable slot), including downstream consequences.
- Before departure, a conflict regulated operational timetable all the way from departure to arrival should be constructed. The level of detail in the conflict regulation is a topic for further investigation, but it should be good enough so that no unexpected negative consequences happen to any train in the railway system.
- The arrival capacity of the destination yard/terminal should be confirmed already at the departure. The arrival capacity should also be continuously updated and transparent.
- The daily operational timetable should be adjusted in order to maximize robustness given the specific situation of the day.
- In case of disturbances, trains and yard operations should be prioritized in a way to secure deliveries to final customers.
- Train drivers should run trains according to the (operational and daily updated) timetable slots.[26]

5.2.2 Real-time Yard Management

ARCC's Deliverable 2.3 aimed at defining the scope, functional and non-functional requirements relating to decision support systems applicable for real-time yard management. Decision-making is considered mainly in the roles of the yard manager and the line dispatcher, keeping in mind the requirements of IM, RU and their customers.

The yard operations management as well as the interaction between the yards, terminals and network management have a significant improvement potential, where optimization, automation and advanced decision support tools can make an important contribution. To accomplish this, the research work has described and analysed the related planning and operational processes in detail. A main future challenge will be to model the decision-making processes in an appropriate software system and integrate with optimisation algorithms. It is intended that a real-time yard management

[26] ARCC D2.2 - Description of business processes of a network management system and the interactions/interfaces with a Real-time Yard Management System, page 56

system can optimise resource-allocation and connect with external systems to contribute to improvements of network planning. ARCC WP2 contributes to this aim by studying the possibility of automatic re-planning of shunting yard operations, especially in combination with train path re-planning. If a Real-time Yard Management System provides optimising automatic decision support, it may also help dispatchers and yard control personnel improve and adapt the current operational plan.

One of the most important requirements for the solution will be to achieve a good user acceptance. In order to get all actors to approve of the decision support system, the solutions generated by the system must be acceptable for all parties.[27]

5.2.3 Real-time Network Management

Freight train operators generally ask for more changes close to operation than passenger train operators. Today there is a challenge to accommodate these without interfering with existing (passenger) traffic. The main innovations of planning activities are related to decision support for strategic, tactical and operational capacity planning to support these requests. In particular, new concepts and algorithms for re-planning and adjustments of train timetables will be implemented.

The involved actors are infrastructure managers, yard or terminal managers and railway undertakings. The perspective is mainly from the infrastructure managers that are responsible for managing the network capacity and timetable. There is an interaction between IM, yard managers/terminal managers and RU both in planning process and in operational traffic.

There is a current digitalization improving processes by better decision support and information exchange. Processes that today are done sequential and slow can in future be done automated and in parallel. Today there are shortcomings in planning Today there are shortcomings in planning and operational processes. These have been documented in ARCC deliverable 2.2 and 3.1.[28]

Innovation Potential FR8HUB

The innovation potential by combining line and yard planning in real-time enables optimising timetables and communication. This is a step to increase automation and produce more effective short-term timetables. This has the potential to improve handling of disturbances in operational traffic by improved decision support and communication, giving us more capacity and increasing the punctuality. *Simulation of increasing speed for freight trains:* Freight trains with the ability of acceleration and braking faster and the ability to travel in a slightly higher speed could increase the capacity on the lines by establishing a more homogenous traffic structure for freight and passenger trains. This will reduce the lead time for freight trains. The parameters used in the simulation can be areas used as requirements when developing the freight locomotive of the future.[29]

Innovation Potential FR8RAIL2

Real-time network management and improved methods for annual and short-term timetable planning will better match the timetable to the wishes from various actors (rail undertakings, yard managers and maintenance actors), allow for changes in a later stage, increase flexibility in

[27] ARCC D2.3 - Modelling Requirements and Interface Specification to Yard Simulation System, page 78
[28] FR8HUB D3.1 State-of-the-art and specification of innovations, demonstrations and simulations, page 17
[29] Proposal FR8HUB, page 22

operational control, and further increase of punctuality and on-time performance in the real-time network management. This increases the overall attractiveness of the railway as a freight transportation mode. Furthermore, by systematic inclusion of disturbance sources as well as operator constraints, the new methods will increase transparency and traceability in the planning process and thus allow a more direct and improved communication between rail undertakings, yard managers, maintenance actors and infrastructure managers.[30]

5.2.4 Intelligent Video Gate Terminals

Beyond real-time yard management, the intelligent video gate in terminals will reduce the lead time and increase the cost-effectiveness in the nodes and connect the traffic management system with a real-time network management.[31]

The intermodal segment relies mainly on the use of containers, swap bodies and semi-trailer trains. The growth of intermodal transport is one of the critical success factors for shifting cargo from road to rail. Today terminal infrastructure operates in peak times at the limit of its capacity. Despite the implementation of several terminal and yard management systems there are a lot of physical checks and manual data collection necessary. To reach a higher degree of automation FR8HUB will focus on developing an intelligent video gate technology to optimize in- and outbound train detection, including automatic identification of train consists and characteristics in line with existing TAF-TSI platforms [32]

The implementation of an IVG in the railway section accelerates and improves the data quality of the inbound processes, reduces dwell times and increases punctuality as well as terminal capacity. It will also reduce complaints about damages in the terminal due to high resolution images already at the time the train is arriving. IVG will also significantly improve safety, integrity of the processes and reliability in the processing of relevant data. This especially in the context with the handling of dangerous goods as problems can be detected faster and more reliable.

IVG focusses on the recognition of all relevant data via optical sensing for load units and wagons. Recognized data will be compared with predefined transport data. It includes also a RFID-reader option for wagon data of chipped wagons. Fast data transfer/communication via open, non-discriminative user interfaces enables user-oriented data handling.

The technology will meet established UIC-/ ILU standards for wagon and ILU identification.[33]

Innovation potential FR8HUB

Intelligent video gate shall lead to a higher degree of automation of terminal relevant processes and more reliability of repeating “every day” processes. The competitiveness of terminal operations in the transport chain is one of the key factors in terms of quality, buffer function and easier access of users to the railway system. The reliability and quality of control processes are very often subject to difficult, time consuming and expensive discussions about different opinions of the market players. The intelligent video gate will help to neutralize all those critical discussions between the partners of the transport chain about the objective conditions of intermodal load units and/or wagons. It will therefore ease and clarify the process of working together.[34]

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[30] FR8RAIL 2 proposal, page 20
[31] FR8HUB proposal, page 9
[32] FR8HUB proposal, page 10
[33] FR8HUB proposal, page 20
[34] FR8HUB proposal, page 22, 23

5.3 Smart Freight Wagon Concepts (TD 5.3)

Innovation Potential FR8RAIL1

The running gear, core and extended wagon design concept will contribute to following strategic areas: better transportation conditions, increased flexibility, longer trains and increased payloads, life cycle cost reduction and increased reliability. In the final stage we will be able to set up characteristics and KPI´s for technical specifications and major wagon concept.

The combination of new wagon design optimized to reduce dead weight, new running gear with better dynamic performance, track friendly and reduced noise, and automatic couplers will enable higher speeds of the freight trains which will enable the better use of network capacity. This will allow a higher use of the wagons and locomotives which will reduce the cost of transportation.[35]

Innovation Potential FR8RAIL2

The combination of a new wagon concept optimized for minimum dead weight and length, a new running gear with improved driving dynamics, low-noise and track friendliness and automatic couplers enables higher freight train speeds and thus better utilization of the network, which reduces transport costs. In addition, the aerodynamic and acoustic optimisation results in more energy-savings and environmentally friendly transport of goods.[36]

5.3.1 Running Gear

The running gear should improve the stability of the wagon and the wear of track and wheel. It will be equipped with disc brakes and with a hydraulic damper for safety and maintenance reasons. Due to steering and lower rolling resistance the noise emission level is expected to decrease significantly.

5.3.2 Core Market Wagon

The core market wagon type is designed for the traditional markets of freight rail transport with heavy goods. Thus, the wagon design is based on a bogie chassis with 4 axles. The key driver is to generate a maximum of payload out of the possible axle load. The chassis with different length does not carry the load directly. The load is containerized in various type of boxes or tank containers. Platform length is foreseen in the range of 10 to 14 m.

5.3.3 Extended Market Wagon

The Extended market wagon EMW should address the LDHV-Segments of the transport market. For these a high payload is not needed. Consequently, the EMW bases on a 2-axle-chassis. The specific costs are driven by the quantity of transport units which can be transported in one train. Therefore, optimized length and reduced tare weight are the main drivers for the mechanical design, so that the maximum length of 750 m can be used in single traction. The length of the loading platform can vary depending on the transport units between 12 and 16 m.

5.3.4 Telematics and Electrification

The new wagon concepts will be electrified, and a dual conduct air pressure supply form the locomotive. This is the bases for creating wagon intelligence and superior braking performance. The wagons do have a Wagon Onboard Unit WBO, which communicates along the train with the control system of the locomotive. With this basic architecture all the beneficial functions like end-of-train

[35] FR8RAIL 1 proposal, page 17
[36] FR8RAIL 2 proposal, page 19

detection, automatic coupling, electronic brake control, conditions-based maintenance, digitalisation of freight booking and surveillance of the transported goods, reefer transport.

Innovation Potential FR8RAIL1

The introduction of telematics in the wagon will enable new integrated services for logistic operations and the fleet management. This will increase the attractiveness of rail mode for special goods which will bring more margin to freight trains operating companies. For the operators and wagon keepers the telematics will allow better and online asset management. Moreover, the basis for condition-based management system will be generated.

Innovation Potential FR8RAIL2

The introduction of telematics in the freight wagons will enable new integrated services for logistic operations and maintenance by means of the wagon intelligence. In Logistics, it will increase the attractiveness of rail mode for special goods which will bring more margin to freight trains operating companies. For Maintenance it will allow condition-based maintenance to change completely the organizational model of maintenance services where maintenance units traditionally work like a production chain reducing the number of human resources at expenses of the availability of the asset. Condition based maintenance will provoke a change of paradigm in maintenance processes and will evolve to a situation where the information about the asset is the driving force and all the operations are focused on reducing asset unavailability and costs.[37]

5.4 New Freight Propulsion Concepts (TD 5.4)

5.4.1 Last Mile Propulsion Systems

Innovation Potential FR8RAIL2

Hybrid propulsion with intelligent energy management system will provide high flexibility and energy efficient operation. The technology will allow to implement innovative energy efficient transport models, with operation on both electrified and non-electrified lines.

5.4.2 Radio controlled distributed Power

Innovation Potential FR8RAIL2

The very long trains running with radio remote controlled distributed power in other continents are very well known, whereas in in Europe, the train length is still limited to 740 m or 750 m in most European countries. Multiple traction exists, but usually in front of the train or in the so-called sandwich mode, with a second train driver in the locomotive at the end of the train. The technology further developed in this project will pave the introduction of long trains up to 1500 m length, thus giving the freight operators the possibility to increase capacity and to set up novel business models and services.[38] The key advantage of this solution is the distribution of power along the train and better exploitation of the available traction units (locomotives).

[37] FR8RAIL 2 proposal, page 20
[38] FR8RAIL 2 proposal, page 20, 21

5.4.3 Freight Loco of the Future

The freight locomotive of the Future aims at developing key technologies for future energy efficient freight locomotives, allowing highest operational flexibility and providing attractive and competitive rail freight services to the final customer.

The key elements are digitalisation, automation in train operation, energy-supplied freight wagons, advanced functionalities and increased productivity. The challenge is to take the freight locomotive to the next level by:

- improving the efficiency of propulsion systems with hybrid technologies and energy storage systems
- improving last mile concepts
- reducing LCCs, including wear
- enabling longer trains up to 1500 meters
- reducing emissions, including noise
- introducing driver advisory systems (DAS)
- enabling autonomous driving

Innovation potential FR8HUB

- Extreme flexibility: operation on non-electrified and electrified lines without the need of changing the locomotive. This requires hybrid propulsion technologies, and includes last mile propulsion systems
- Competitive rail freight services: Remote control for distributed power, thus, allowing the increase of the train length up to 1,500 m and consequently improving the cost efficiency of rail transport. This includes also technologies that reduce LCC (e.g. low wear locomotive bogie)
- Energy efficiency: Recuperation of braking energy as much as possible, store it onboard and reuse it whenever required, for traction purposes, for peak shaving or to supply auxiliaries and others

The concept of the last mile propulsion system on a mainline electric locomotive (an electric locomotive equipped with a small diesel engine covering similar needs and first proposed by Bombardier Transportation few years ago) was a disruptive and successful innovation, giving the customers the independence from shunting operators. While in FFL4E a full electric last mile propulsion system with up to 500 kWh energy and higher peak power in the range of 1 MW is developed, in FR8HUB further technologies and hybrid approaches will be investigated. They will offer to the customer even higher independence (no empty battery, but more power that on today's systems) with better energy efficiency.

The integration of energy storage systems in the freight locomotives, larger ones for traction on dual mode locomotives, small and decentralized ones for feeding systems, and the implementation of power peak shaving algorithms will lead to a higher energy efficiency and thus to reduced overall operational costs. Building on these technologies, many innovations are expected and will open the field to innovative business models.[39]

[39] FR8HUB proposal, page 23

5.4.4 Hybridisation of Legacy Shunters

Innovation potential FR8HUB

The hybridisation of legacy shunters is part of the strategic activities of Shift2Rail IP5 in order to optimize the freight traffic flows in marshalling yards. From an operational viewpoint, the hybrid shunter could take over two jobs – replace old shunters and operate in mainline traction services. Whichever deployment is ideal will be analysed for the technologically most suitable concept per base locomotive. The resulting gain in flexibility from hybridisation comes at a minimum cost and will benefit all European freight hubs. To maximize this flexibility, hybrid shunters will also be assessed for further automation.

The hybrid shunter is one of the most efficient and eco-efficient propulsion solutions. In the heavy power class required, Fr8Hub aims for the technological break-through for retrofitting. Also, the hybrid is open to test further innovation in the consecutive Shift2Rail projects: When more innovative technologies are mature, they can be implemented into the hybrid concept e.g. replacing the diesel engine. A state-of-the-art container/modularisation concept shall be implemented to minimise downtimes of locomotives and to improve maintainability of the locomotive.[40]

[40] FR8HUB proposal, page 23

6 Expected Impact of Technologies and Solutions

6.1 Digitization & Automation Rail Systems (TD 5.1)

6.1.1 Condition Based Maintenance

Expected impact FR8RAIL1

Condition based and predictive maintenance based on status from asset intelligence will be ground-breaking innovation with sustainable cost and quality improvements based on the intelligent use of accurate information arising from telematics and electrification part of the project.[41]

Expected impact FR8HUB

Condition based maintenance based on status from asset intelligence will be ground-breaking innovation with sustainable cost and quality improvements based on the intelligent use of accurate information arising from the monitoring system to be developed within the project.

Reduction of operational cost due to reduction in maintenance costs.
Maintenance related expenses are one of the largest contributors to the LCC of the railway system. For example, DB Netz in 2012 estimated the maintenance costs to be over 50 % of the LCC, without the effect of unavailability. On the other hand, in dense traffic lines the availability of the lines is the key parameter that monitors the maintenance schedules. The cost of unavailability and the penalties that maintenance service providers suffer are huge and impact directly in the profitability of the companies.

Consequently, maintenance service providers of train operating companies are very concerned optimizing on one hand the cost of maintenance services and on the other the risks associated to the operation. The FR8HUB project will develop technologies and processes as a part of the overall CBM strategy that will optimize cost while maintaining the safe operation. The technologies developed in the area of CBM are expected to reduce the maintenance costs in a range of 10 %. This will contribute to reduce the operational costs of rail freight transportation.[42]

Main influence on

KPI	Reason
LCC	Lower operational costs due to lower maintenance costs
Punctuality	Higher reliability of assets in operation
Capacity	-

Benefits mainly for

Shipper	Forwarder	RU/operator	Wagon keeper	IM/Y/T	Customer

[41] FR8RAIL 1 proposal, page 18
[42] FR8HUB proposal, page 24

6.1.2 Automatic Coupling / Digital Automatic Coupler (DAC)

Expected impact FR8RAIL1

The automated coupling and processes in the terminals/nodes will improve efficiency, environmental impacts as enabling longer trains and safety related impacts with regards to human factors.

Expected impact FR8RAIL2

The foreseen research activities are expected to improve the overall efficiency of freight trains by allowing to run longer trains, reduce train composition times and integrate data and electrical transmission.

- Higher load capacity will allow longer trains compositions (up to 1500 m), operating at higher speeds.
- Reduced train composition times (up to 30 %): Remote uncoupling allows automating vehicle composition operations, minimizing manual intervention, increasing safety, and thus, reducing operational costs.
- Data and electrical transmission of energy and data will allow the installation of sensors in the trains, this is required for Condition Based Maintenance and to remotely monitor the status of the goods. The value for the automatic coupler is that there is no additional train configuration time needed.[43]

Main influence on

KPI	Reason
LCC	Lower personnel costs
Punctuality	Faster train configuration, lower lead time
Capacity	-

Benefits mainly for

Shipper	Forwarder	**RU/operator**	Wagon keeper	**IM/Y/T**	Customer

6.1.3 Freight ATO / C-DAS

Expected impact FR8RAIL2

- Enables smooth freight traffic by improving information exchange between TMS and DAS on the RU side.
- Realizes energy savings of up to 10 %.
- Develops concept for standardization of European connected DAS[44]

[43] FR8RAIL 2 proposal, page 21
[44] FR8RAIL 2 proposal, page 23

Main influence on

KPI	Reason
LCC	Energy savings, lower personnel costs due to (partly) automated processes
Punctuality	Better information between TMS (IM) and DAS (RU)
Capacity	Better information between TMS (IM) and DAS (RU)

Benefits mainly for

Shipper	Forwarder	**RU/operator**	Wagon keeper	**IM/Y/T**	Customer

6.2 Digital Network Management (TD 5.2)

6.2.1 Improved Methods for Timetable Planning

Expected impact FR8RAIL2

- Providing processes and tools that reduce the need for freight trains to run outside their planned timetable channel. This decreases the need for operational rescheduling.
- Developing timetable adjustment methods that can handle the needed flexibility of the freight train operation without causing disturbances for other trains; this increases the competitiveness of the rail freight system,
- Adjusting timetables to actual operational needs of the freight operators, thereby improving the perceived punctuality for freight trains by at least 10-15%.

Main influence on

KPI	Reason
LCC	-
Punctuality	Possibility to adjust timetables to meet actual needs
Capacity	Better long- and short-term timetable planning

Benefits mainly for

Shipper	**Forwarder**	RU/operator	Wagon keeper	**IM**	**Customer**

6.2.2 Real-time Yard Management

Expected impact ARCC

Among the various ways of automating processes in nodes, the automation of disposition/dispatching processes in marshalling yards and terminals, including interaction with the traffic management system, has a major impact in terms of reducing lead times and improving the punctuality and cost-efficiency of rail freight.

Main influence on

KPI	Reason
LCC	-
Punctuality	real-time information of actual demand
Capacity	Better utilisation of assets, real-time information of actual demand

Benefits mainly for

Shipper	Forwarder	RU/operator	Wagon keeper	**IM/Y/T**	Customer

6.2.3 Real-time Network Management

Expected impact FR8HUB

Optimise the decisions and the resulting operational processes in real-time.
A new method based on high-level capacity analysis of both yards and lines will be developed. The aim of the method is to provide optimised decision support with accurate capacity analysis results in real-time, making it useful for analysis of changed technical requirements in yards and lines. The goal of the method is to be useful in an office setting. In this context, a maximum execution time for the analysis is within 15 minutes of runtime, with a significantly lower average execution time and useful analysis results delivered within a few minutes. The accuracy of the method will be validated using microscopic traffic simulation.[45]

Increase the capacity of mixed traffic.
As case studies, the method will be used for analysis of heterogeneous traffic on two important lines in the TEN-T corridor between Sweden and Germany. Using both analytical methods and micro-simulation studies, the increased freight speed on these two lines will be investigated, with the goal of increasing capacity and reducing running and waiting times as well as delays for all traffic on the considered lines. Further, the costs and benefits of the technical requirements for this will be analysed.[46]

Expected impact FR8RAIL2

- Providing processes and methods increases holistic network management, by e.g. improving the interaction between line and yard planning. This gives more flexible and competitive train paths for freight trains and better punctuality for passenger and freight trains.
- Specification of demonstrator for Real-time network management that includes and utilizes modern decision support technologies and thereby defines requirements on other supporting activities and systems, e.g. data need. This gives more flexible and competitive train paths for freight trains and better punctuality for passenger and freight trains.
- Better possibilities to meet the various needs and wishes regarding track capacity from all actors (rail undertakings of various kind, yard managers and management actors). The flexibility is most important for the freight traffic.[47]

[45] FR8HUB proposal, page 24
[46] FR8HUB proposal, page 24
[47] FR8RAIL 2 proposal, page 22

Main influence on

KPI	Reason
LCC	-
Punctuality	real-time information of actual demand
Capacity	Better utilisation of assets, real-time information of actual demand

Benefits mainly for

Shipper	Forwarder	RU/operator	Wagon keeper	IM/Y/T	Customer

6.2.4 Intelligent Video Gate Terminals

Expected impact FR8HUB

The IVG has an important impact on main quality issues along the transport chain. Check procedures get highly accelerated through:

- automated data collection and validation with pre-defined transport data
- improvement of data quality
- acceleration of in-/outbound train documentation for damages and conditions
- information to users about critical differences from pre-defined data
- reduction of time required for checks on a train of 700 m length from approx. 40 min down to approx. 15 min, this makes load units quicker available to already waiting trucks, especially in peak times
- reduction of dwell time for trains, ILU and trucks
- immediate use of recognized date for optimized reloading
- noticeable reduction of damage claims of up to 75%, that are often exploited due to patchy in-/outbound checks, IVG provides evidence and real-time documentation
- improvement of safety, integrity of the processes, especially due to the handling of dangerous goods
- Increase terminal peak capacity by faster workflow and reduced dwell time for trains, trucks and ILU up to 15%.

This will result in more effective and efficient terminal processes.[48]

Main influence on

KPI	Reason
LCC	-
Punctuality	Lower lead time, due to reduced dwell times in terminal
Capacity	Reduced dwell time for trucks and trains

[48] FR8HUB proposal, page 25

Benefits mainly for

Shipper	Forwarder	**RU/operator**	**Wagon keeper**	**IM/Y/T**	Customer

6.3 Smart Freight Wagon Concepts (TD 5.3)

Expected impact FR8RAIL1

There are three areas in FR8RAIL 1 which ensure the safe transportation of dangerous goods; telematics, wagon design and condition-based maintenance. In telematics FR8RAIL will include wagon monitoring system and integration of cargo monitoring system to the benefit of dangerous goods.

FR8RAIL 1 will develop technologies for the wagon design that will enhance the aerodynamic behaviour and therefore reduce energy consumption. In parallel, FR8RAIL will develop new concepts for the wagon based on lightweight materials. This will also contribute to reduce the energy consumption. This objective will directly reduce the operational expenses of both infrastructure and railway operators.[49]

6.3.1 Running Gear

The objective for the running gear is high running stability in combination with better steering of the wheelset, so that wear and rolling resistance can be reduced. The noise emission should then decrease. A new suspension and damping system is expected to further improve noise emissions.

Main influence on

KPI	Reason
LCC	Reduced energy cost and less wear on track and wheels
Punctuality	-
Capacity	Lower noise emission level

Benefits mainly for

Shipper	Forwarder	**RU/operator**	**Wagon keeper**	**IM/Y/T**	Customer

6.3.2 Core Market Wagon

Expected impact FR8RAIL2

- Reduction of the weight of freight wagons, to maximize the payload/ deadweight ratio.
- Significantly contributes to the improvement of reliability.
- reduces the total operating costs for the vehicle and infrastructure by up to 20 % combining novel design of running gears, predictive maintenance methods and improved aerodynamics.
- Improved acoustical behaviour of wagons, reduced noise pollution of the residents down to the level of passenger trains

[49] FR8RAIL proposal, page 18

- Provides standard mechanical and electrical interfaces for modular, scalable wagon design for operational interoperability.[50]
- Offers the possibility to be equipped with a drive and control unit to allow automized operations in sidings and stations without shunting locomotives.

Main influence on

KPI	Reason
LCC	Higher invest per wagon, but - higher productivity in transport operations - less energy consumption - less infrastructure wear leads to lower LCC;
Punctuality	Higher reliability because of fully monitored components/assets
Capacity	Higher utilisation of rolling stock, due to better payload-dead weight-ratio; Better network utilisation and improved wagon turnover in general due to automized processes in the operation

Benefits mainly for

Shipper	Forwarder	RU/operator	Wagon keeper	IM/Y/T	Customer

6.3.3 Extended Market Wagon

Expected impact FR8RAIL2

- Reduction of the weight of freight wagons, to maximize the payload/deadweight ratio for optimized intermodal applications to beat the competition from the road
- Significantly contributes to the improvement of reliability.
- reduces the total operating costs for the vehicle and infrastructure by up to 30 % combining novel design of running gears (reduced no. of axles, better steering and suspension), predictive maintenance methods and improved aerodynamics.
- Improved acoustical behaviour of wagons, reduced noise pollution of the residents down to the level of passenger trains
- Provides standard mechanical and electrical interfaces for modular, scalable wagon design for operational interoperability[51]
- Is ready for ETCS L3 because of its integrated Safe-Train-Integrity system.

[50] FR8RAIL 2 proposal, page 22, 23
[51] FR8RAIL 2 proposal, page 22, 23

Main influence on

KPI	Reason
LCC	Higher invest per wagon, but - much higher productivity - less energy consumption - less infrastructure wear leads to lower LCC;
Punctuality	Higher reliability because of fully monitored components/assets
Capacity	Higher utilisation of rolling stock, due to better payload-dead weight-ratio; Higher speed → access to day routes leads to better network utilisation and improved wagon turnover in general

Benefits mainly for

Shipper	Forwarder	RU/operator	Wagon keeper	IM/Y/T	Customer

6.3.4 Telematics and Electrification

Expected impact FR8RAIL1

Telematics and electrification will enable better track and trace capabilities to the benefit of segments such as temperature goods and dangerous goods but also the equipment itself.
The specifications for an intelligent automated coupling is one of the key elements in turning the freight wagons into being intelligent as well.[52]

Expected impact FR8RAIL2

- Reduction of maintenance costs (material and labour) in the respective countries to enable a more reliable service as well as a more competitive cost structure thanks to the information collected by the wagon intelligence.
- Development of algorithms to determine the necessity of a component's replacement to avoid premature replacements.
- A significant reduction of derailments through further CBM implementation.
- Reaching a 10 % reduction of maintenance operational expenses to increase rail freight business competitiveness.
- Improve operational efficiency by eliminating unnecessary maintenance activities.
- Enhance competitiveness of traffic carrier “rail” by offering more and reliable freight capacities.[53]

[52] FR8RAIL proposal, page 18
[53] FR8RAIL 2 proposal, page 21

Main influence on

KPI	Reason
LCC	Lower maintenance costs
Punctuality	Less disturbances due to unforeseen breakdowns (i.e. derailments)
Capacity	-

Benefits mainly for

Shipper	Forwarder	RU/operator	Wagon keeper	IM/Y/T	Customer

6.4 New Freight Propulsion Concepts (TD 5.4)

6.4.1 Last Mile Propulsion Systems

Expected impact FR8RAIL2

- Provides high operational flexibility by implementing powerful dual power locomotives capable to run on electrified and non-electrified lines.
- Provides energy efficient and environment-friendly propulsion systems mainly by recuperating braking energy with onboard energy storage systems, such as e.g. Li-Ion batteries or other technologies
  - Power boost feature leading to a 20 % diesel engine downsize, and hence, ease the use of medium size engines which are more likely to meet restrictive emission standards.
  - Energy manager feature leading to reduce up to 20 % the overall energy consumption thanks to energy recovery capability and more efficient diesel engine operation.
  - Electric mode feature permitting disconnection of diesel engines under idle or low power demanding situations (e.g. marshalling yards) which accounts for over 40 % of time according to ARR and EPA reports.
  - Suppling auxiliaries and other loads.
- E-Locos with battery-based range extender allow operation in shunting in terminal areas (no energy supply over catenary system available) and save therefore operational cost for change of the traction in the short term. Moreover, this double supply E-Hybrid overs the perspective of not having a shunting locomotive anymore in the future.
- Automated functions for the train preparation and start of mission phases will increase efficiency and reduce operational costs by up to 50 %.[54]

Main influence on

KPI	Reason
LCC	In total lower invest in the fleet due to more operational flexibility
Punctuality	Less dwell times, no additional shunting process in yards and terminals
Capacity	-

[54] FR8RAIL 2 proposal, page 23

Benefits mainly for

Shipper	Forwarder	**RU/operator**	Wagon keeper	**IM/Y/T**	Customer

6.4.2 Long Trains up to 1500 m

Expected impact FR8RAIL2

- Increases productivity of rail operations rapidly by doubling maximum train length to 1,500 m on dedicated lines
- Enhances train weights and lengths up to 740 m by introducing Distributed Power for unattended pushing locos[55]

Main influence on

KPI	Reason
LCC	Sharing of track tariff between two or more trains under the premises that the current tariff system is applicable for trains with higher length and load.
Punctuality	No influence
Capacity	Negative influence on network capacity due to non-interoperability with the current network design

Benefits mainly for

Shipper	Forwarder	**RU/operator**	Wagon keeper	IM/Y/T	Customer

6.4.3 Freight Loco of the Future

Expected impact FR8HUB

The integration of on-board energy storage systems, capable of recuperating braking energy, and feeding the traction chain but also other components and systems, and the implementation of peak power shaving algorithms will lead to better environmentally friendly performance. Thanks to these concepts, FR8HUB expects to reach the goal of an increase of energy efficiency by 10 %.

Furthermore, thanks to innovative technological approaches for the next generation of last mile propulsion systems, operational flexibility and efficiency will be massively improved.[56]

Main influence on

KPI	Reason
LCC	Lower operational costs due to better energy efficiency; In total lower invest in the fleet due to more operational flexibility
Punctuality	-
Capacity	-

[55] FR8RAIL 2 proposal, page 23
[56] FR8HUB proposal, page 26

Benefits mainly for

Shipper	Forwarder	RU/operator	Wagon keeper	IM/Y/T	Customer

6.4.4 Hybridisation of Legacy Shunters

Expected impact FR8HUB

Hybridisation as a retrofit activity will enable rail freight to quickly react to the competitive pressure. Following FR8HUB the implementation will be reduced to a few weeks per unit based on the known configurations.

The hybridisation of legacy shunters can lead to a reduction of CO2 and of energy consumption of 20 - 30 % in the long-term, in combination with start-stop and state-of-the-art technologies. A first calculation of the profitability and energy saving potential by comparing the performance of a conventional shunting locomotive with hybrid retrofitted vehicle gave this significant performance indication.

Especially, within the higher velocities the benefit from the hybrid system is higher compared to lower velocities. This efficiency in combination with the battery storage is expected to ensure an energy saving in terms of fuel savings of more than 20 %. Reduced fuel consumption means besides the reduction of LCC cost by roughly 10 % also the significant improvement of the ecological footprint. The improved efficiency of the hybrid system resulting in up to 30 % fuel savings.

Additionally, the hybrid system, enhanced through condition monitoring, will be flexible for deployment under or not under catenary, in light, medium and heavy duty. Taken together with automation, the planning time will be reduced, and flexibility and operational efficiency be maximized.[57]

Main influence on

KPI	Reason
LCC	Lower operational costs due to less energy consumption
Punctuality	-
Capacity	-

Benefits mainly for

Shipper	Forwarder	RU/operator	Wagon keeper	IM/Y/T	Customer

[57] FR8HUB proposal, page 25, 26

6.5 Summary of the Benefits for the different Stakeholder Groups

All technologies and solutions serve to increase the competitiveness of the entire railway system. They all contribute - to varying degrees - to improving the LCC, to increasing capacity or to improving punctuality in the system.

As discussed separately in the previous chapter, individual solutions contribute to this to varying degrees. In addition, the advantages generated do not develop to the benefit of all stakeholder groups. Table 3 below shows which group benefits directly/mainly from which technology or solution.

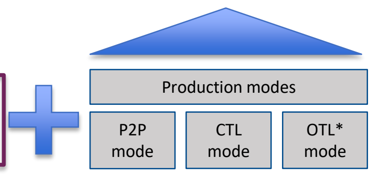
Table 3. Tabular presentation of benefitting stakeholders by solution

Full exploitation of benefits require production modes with high running performance!

Solution	Retrofit possible	Shipper	Forwarder	RU/ operator	Wagon keeper	IM/Y /T	Customer
CBM	yes			X	X		
Automatic Coupler	yes			X		X	
ATO / C-DAS	yes			X		X	
Timetable planning	yes	X	X			X	X
Yard management	yes					X	
Network management	yes	X	X			X	X
IVG	yes					X	
Running gear	no			X	(X)*	X	
CMW	no	X	X	X	(X)	X	X
EMW	no	X	X	X	(X)	X	X
Telematics & Electrification	yes	X	X	X	(X)	X	X
Last mile propulsion	no			X		X	
Distributed power	no			X			
Loco of the future	no			X			
Hybridisation of legacy shunters	yes			X			

)* depending on rental contract conditions

- Lower specific costs
- Better utilisation of assets
- Better utilisation of network
- Lower wear on track and running gear
- Lower energy consumption
- Higher punctuality



It is also clear that the full potential can only be realised if new or stringent production systems are implemented with the CMW and EMW wagon technologies. All actors in the sector will benefit from this.

7 Assessment of expected Benefits and Dependencies of Key Technologies

7.1 KPI-Modelling in Shift2Rail Impact-Projects

7.1.1 Objectives and Reference Scenarios

While the experts (TD leaders and project staff) have considered and evaluated the improvement potentials of their solutions mostly isolated from each other, the effect on the overall system takes place in the CCA of Shift2Rail, here in the IMPACT-1 and IMPACT-2 projects. WP1 in FR8HUB supported here to get the overall picture.

The overall target KPIs were defined in the Master Plan with three quantified targets:

- + 100 % in capacity,
- - 50 % in LCC,
- + 50 % in reliability

as it is one of the goals of Shift2Rail to significantly increase the competitiveness and attractiveness of rail freight in the land-based freight business.

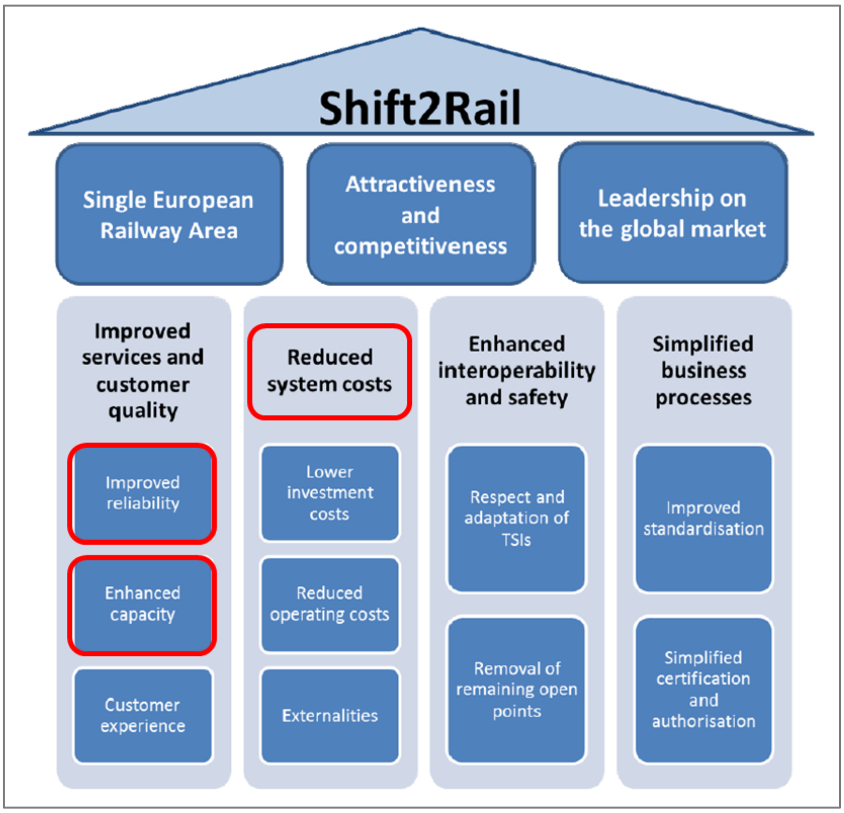


Figure 11. Overall objectives of Shift2Rail

The KPI assessment is carried out by the CCA-project IMPACT-2 WP4 in collaboration with the IP-projects for the four traffic segments, so called system platform demonstrators (SPD):

- High speed
- Regional
- Urban
- Freight → IP5

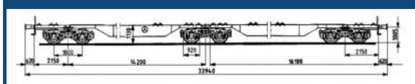
First, the reference scenarios for the operational area (single wagon load, block train operation, combined traffic) as well as the basic technical equipment for rail freight traffic were defined and provided with basic values.

Table 4. Reference parameters for average national and European freight transport

Reference parameter	Unit	Freight transport category		
		Single wagon load	Customer Block train	Combined traffic
Share (of trains)	%	25	40	35
Average transport distance	km	600	600	600
Average train length	m	450	450	450
Max. pay load	t	1000	880	960
Loading factor*	%	50	40	60
Average no of wagons		18	17	13
Max. speed (today/future)	km/h	120	120/ 160	120/ 160
Average main line speed (incl. stops)	km/h	50	50	55
Average transport speed	km/h	13	20	25
No of marshalling points		3	0	0,5
Wagon types		CMW	CMW & EMW (90:10)	EMW
Total operational cycle time for one trip for locomotives/ wagons	h	45 / 75	25 / 75	25/ 55
Average km per year for locos/ wagons	km/h	100.000 / 60.000	100.000 / 60.000	180.000 / 90.000

What is striking about this compilation of empirical values of rail freight transport is the low degree of utilisation in terms of length, tonnes and load factor of the customer-related block train (Customised Block Train). Today, mainly factory transports are bundled under this heading. This has little in common with a block train in the sense in which this term is used in [Reference D1.1 FR8Rail]. There, the block train is defined as a fixed train formation whose transport capacity is marketed on fixed routes and which is precisely not customer-specific. We will come back to the effect of this definition on the specific parameters.

Table 5. Reference freight wagon types

Reference parameter	Unit	Wagon types	
		Core market 	Extended market 
Wagon Type		**Habbins 345**	**Sggrms 715**
Tara weight	t	26,5	30
Gross weight	t	90	94
Max. pay load	t	63,5	64
Max. axle load	t	22,5	20
No of axles		4	6
Length	m	23,3	34,0
Max. speed	km/h	120	120

In addition to the operational modes and technical equipment handling times or process times in general were added to different procedures along one route (see Figure 12). The long process times and the numerous process steps lead to very low average transport speeds which is one major competitive disadvantage of rail freight today. Today, an average speed of 50 km/h on the main line plus additional process steps and times lead to an average transport time 27 to 48 hours for a route length of 600 km. Thus, the average speed in relation to the total transport distance is between 13 and 25 kilometres per hour. Besides this poor performance in terms of time it considerably reduces the productive utilisation of wagons, locomotives, staff, yards and terminals. This extremely low productivity has, moreover, also led in recent decades to a situation in which procurement has been largely influenced by the valuation of acquisition costs – the lower the better – and has therefore not resulted in any significant new technologies being introduced.

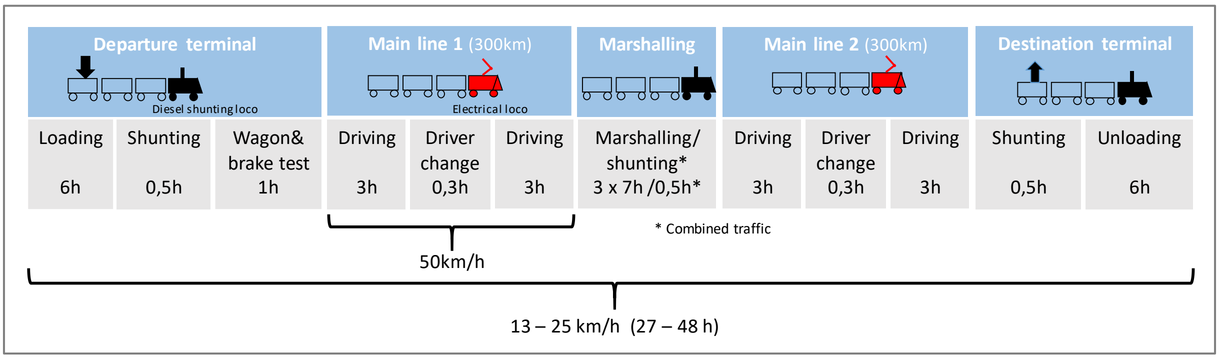


Figure 12. Freight transport process and reference times

In addition to the process times, parking times for wagons (30h) and locomotives (10h) were added in a further step to evaluate the effective use of these assets for the base scenario.

7.1.2 Assumptions for the Simulation

Table 6. Different kind of LCC impact by TDs

Kind of LCC impact	LCC-parameter	TD	Assumed Improvement
Direct LCC-impact	Capital costs Maintenance costs Energy costs Train driver costs	TD 5.3 Wagon, 5.4 Loco TD 5.3 Wagon, 5.4 Loco TD 5.1 DAS, 5.3 Wagon TD 5.1 ATO	*See next table*
Impact on transport process time	Loco-km per year Wagon-km per year	TD 5.2 Transport management TD 5.3 Wagon	+45 % +30 %
Impact on max. pay load	Max. wagon pay load per train length	TD5.3 Wagon	+15 % CMW +35 % EMW
Impact on wagon loading factor	Loading factor	TD5.2 Transport management	10%

Table 7. TDs with direct impact on LCC

TD	Asset	Cost component	Impact	Explanation
5.1 CBM	CBM Locomotive	Maintenance costs	-10 %	Target
5.1 ATO	Operation	Train driver costs	-90 %	ATO on main lines
5.1 DAS	Operation	Energy costs	-10 %	Energy efficient driving, less stops
5.3 Wagon	Core market wagon	Capital costs	+20 %	Prototype, digitalisation, automatic coupling
		Maintenance costs	- 5 %	CBM
		Energy costs	0 %	
	Extended market wagon	Capital costs	+20 %	Lightweight, digitalisation, automatic coupling
		Maintenance costs	- 25%	Reduced axles, CBM
		Energy costs	-40% at equal speed	Improved aerodynamics, but higher speed
5.4 Loco	Main line loco with last mile propulsion	Capital costs	+10%	Last mile propulsion
		Maintenance costs	+10%	Last mile propulsion

The reduction of transport time (see Figure 13) is not only an essential lever to increase the capacity of the network infrastructure, it also has a noticeable impact on the LCC. This is because shorter transport times also increase the effective use of assets - i.e. productivity. Conversely, less rolling stock is required for the provision of services, which reduces the investment share of the LCC.

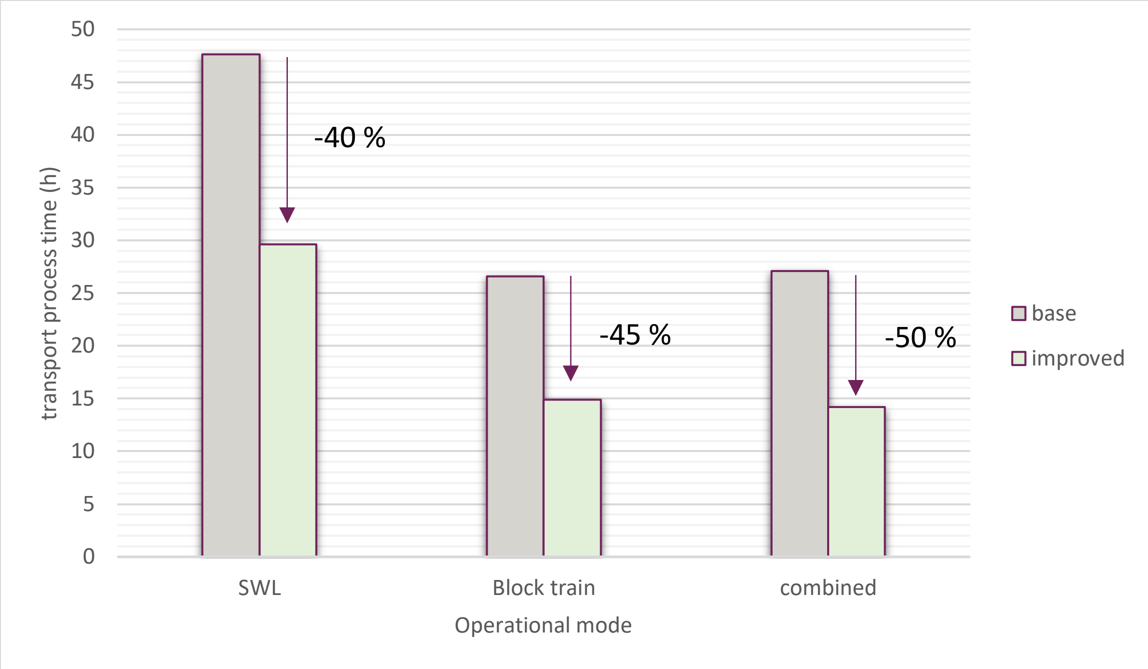


Figure 13. Improvements of transport time by operational mode

7.1.3 Results for specific Cost of Transport (LCC approach)

By means of the IP5 solutions the LCC for freight, measured in €/t/km, can be reduced by about 35 % across all operational modes if all innovations are implemented in the market (see Figure 14). This reduction of LCC is mainly driven by

- Improved utilisation of rolling stock material (locos and wagons (km/a)) due to reduced transport process time in the terminals, yards and on the main line (prerequisites: IVG, wagon electrification, automatic coupling, real time yard and network management, increased wagon speed and ATO)
- Increased pay load due to reduced wagon tare weight
- Automatic train operation (GoA4) on main line
- Improved loading factor due to digitalisation of processes

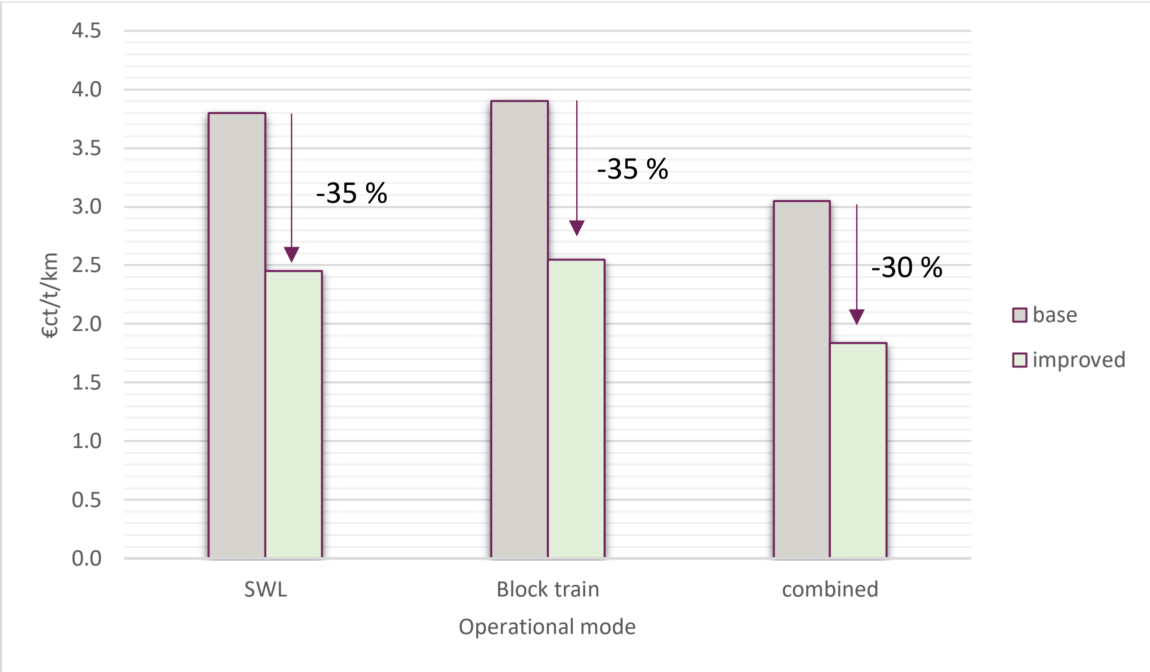


Figure 14. Improvements of LCC by operational mode

It should also be mentioned that the higher specific costs of the customer-related block train shown in the simulation are due to the choice of parameters and the measured variable. This has already been explained in the empirical data. The costs are measured in €ct/tkm. As these trains are usually customer-specific trains for factory transports, the tonnage is lower relative to many single wagon transports and the load factor is below 50% due to the missing load for the return transport. The potential of a real block train service in the P2P and CTL modes is not reflected by this consideration. This will be discussed in chapter 7.2.

7.1.4 Results for Capacity

This key performance indicator is determined by two inputs – the capacity of the train and the capacity of the line. Thus, not only IP5 solutions are relevant to raise the capacity of the railway system. But also, solutions from IP2 (e.g. ETCS level 3) must be considered. The following table shows the impact of IP5 solutions on capacity gains.

Table 8. TDs with impact on freight capacity

TD	Demonstrator	Parameter	Assumed capacity Impact	Remark
5.2 Transport management	Real time network management	Loading factor	+ 10%	
5.3 Wagon	CMW EMW	Pay load per train length	+ 15% + 35%	Due to reduced tare weight
	Wagon electrification	Line capacity	+ 10%	Additional daytime slots for fast freight trains with improved braking system
5.4 Locomotive	Long freight train	Train length	+ 15%	50% of trains shorter than 350m (< 30%) are coupled on high density lines
Total Impact IP5			**45 – 70%**	

7.1.5 Results for Punctuality

The punctuality of a train is influenced by numerous factors, as shown in Table 9:

Table 9. TDs with impact on punctuality

TD	Demonstrator	Delays due to	Parameter
5.1 Digitalisation	ATO	Train driver unavailability	Train driver unreliability
	CBM	Loco failure	Main line loco unreliability
5.2 Transport management	Intelligent video gate	Process delays	Terminal unreliability
	Real time network management	Main line delays	Main line unreliability
	Real time yard management	Process delays	Yard unreliability
5.3 Wagon	CBM/ Intelligent wagon	Wagon failures	Wagon unreliability

Initial assumptions are that punctuality will increase from 70 to 80%. However, these significant improvements presuppose that the train uses its intended slot. The switch to an alternative slot, on the other hand, is marked by further dependencies. The on-time disposition of the train drivers is a decisive factor here.

7.2 Sensitivity Analysis with Cost Model for Rail Freight Transport

7.2.1 Idea and Proceeding

The previous chapter discussed how the technical innovations from Shift2Rail affect the costs of rail freight transport. However, the underlying calculation model can also be used to simulate further effects and, in particular, to estimate the economic impact of the production modes from FR8Rail in combination with technical innovations. This will be done with the parameter study in this chapter. For this purpose, the parameters of the cost model are adjusted accordingly and the results determined in this way are compared with each other.

In addition to the effect of individual measures, it is also a question of comparing entire production processes with their technical solutions in order to be able to correctly assess the entire potential of the Shift2Rail innovations.

7.2.2 Distance Efficiency an underestimated Parameter

A previously undiscussed factor influencing transport costs is the ratio of trans-distance to the actual distance travelled. It is obvious that the modes of transport are tied to the infrastructure; this also applies to the aircraft, which cannot provide transport services without airports. As the crow flies, distance is therefore theoretically but not practically relevant as an absolute reference, especially when land transport in Europe is to be compared.

Since the road network is much better developed and every relevant delivery point can be reached by road, the road/rail comparison is based on the transport distance in road kilometres.

The rail network, on the other hand, is much more widely spread across the country and has only a limited number of access points at which goods can be loaded and unloaded. In addition, the railway network is much older than the road network and therefore no longer corresponds to the changing freight traffic flows in terms of capacity, transport relations and loads. As a result, a longer transport distance in train-path kilometres must be assumed for the same transport compared to road. For this reason, the specific transport costs in tkm from chapter 7.1 are not suitable for the comparison of road and rail. In a classical goods train production model with multiple changes of train configuration as is the case in single wagon transport, this can have a significant impact on transport costs because the train formation facilities for today's shunting are only located in a few places. The distance efficiency defined as the quotient of the transport distance of road compared to rail can be significantly lower, as the fictitious example in the following figure shows.

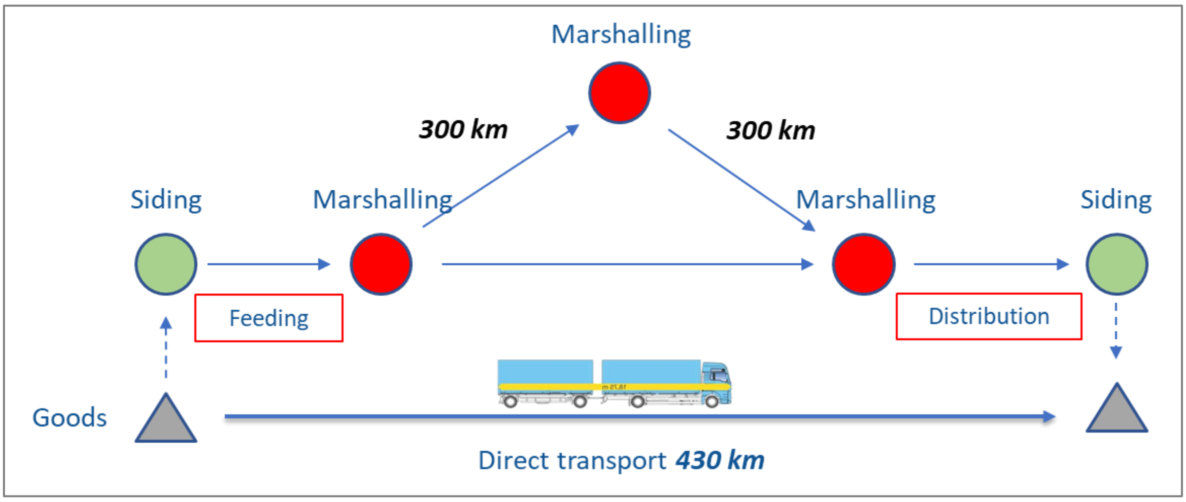


Figure 15: Distance efficiency

In the case shown, the distance efficiency is only a good 70%. This means a 40% mark-up on the transport costs per tkm, if the distance kilometres of the road used by the forwarder as a reference are taken as a basis.

This example shows that in a direct comparison, rail has a structural and economically irremediable disadvantage compared to road. This disadvantage can be reduced, but not completely eliminated, by better positioning of access points to the rail network and correspondingly modified production processes as proposed in Chapter 3. In this respect, it is important to concentrate on attractive transports and routes where rail as a means of mass transport can play out its advantages over road.

The influence of distance efficiency is similar to that of the load factor in relation to the payload, as the calculation has shown. However, in tonne-kilometres, this effect can only be used for heavy goods in mass transport, i.e. precisely in those market segments in which the road, from which market shares are to be taken, does not show any pronounced strength.

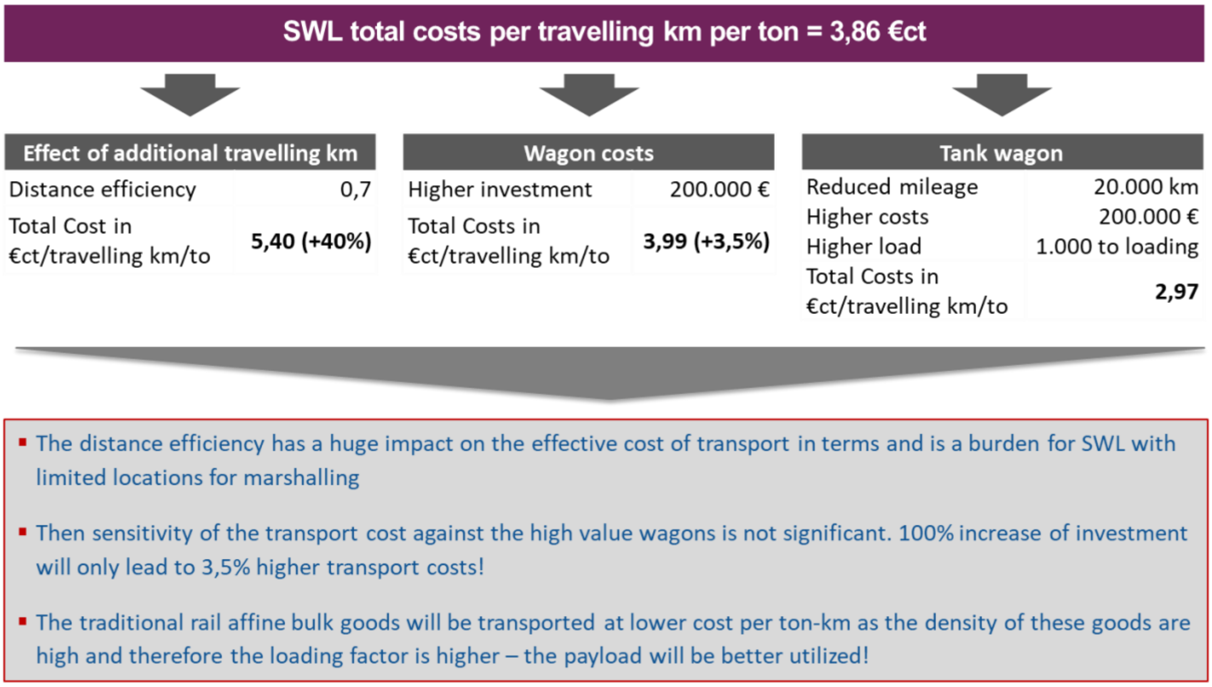


Figure 16: Sensitivity of transport costs

In contrast, the sensitivity analysis showed that the procurement price of freight wagons has no significant influence on the transport costs per tonne-kilometre. Even in less efficient single-wagon transport, a doubling of the wagon price would only have a 3.5% impact on transport costs, all other things being equal. The permanent focus on favourable acquisition costs of freight wagons can therefore not be explained by the striving for competitiveness of rail freight transport. This kind of "cost efficiency" is not relevant in the big picture. It must rather be assumed that the cost optimisation of the freight wagon at the well-known low technical level of the 1950s up to the undermining of entire value-added structures - here above all the development and marketing of the manufacturers must be mentioned - corresponded to the economic logic of the wagon owners. However, their share of value creation in the overall system is insignificant. Nevertheless, the procedure is understandable from the economic logic of the rental business, because for the wagon keeper the wagon represents by far the largest investment. In addition, as a result of the very high proportion of debt capital in this sector, the creditors/capital market exert strong control.

From the perspective of the overall rail freight system, however, the focus on low acquisition costs of an important means of production without looking at its other characteristics remains incomprehensible. This can also be counted among the structural disadvantages of the sector.

7.2.3 Parameter Study for SWL Traffic and OTL

A further sensitivity analysis was carried out for single wagonload traffic. In the process, 5 influencing variables were varied:

1. process lever: omission of shunting/train formation.
2. lever payload: 25% higher payload due to lower empty weight of the wagons
3. lever mileage: 100% higher mileage of the wagons
4. lever distance: improvement of distance efficiency to road level
5. technology lever: 5 technical improvements
   - Condition-oriented maintenance with diagnostic systems,
   - automatic procedure GoA 4
   - Automatic coupling
   - Real-time yard management
   - Better train aerodynamics.

The results are shown in the following figure. The initial situation corresponds to that of Table 4 from chapter 7.1.

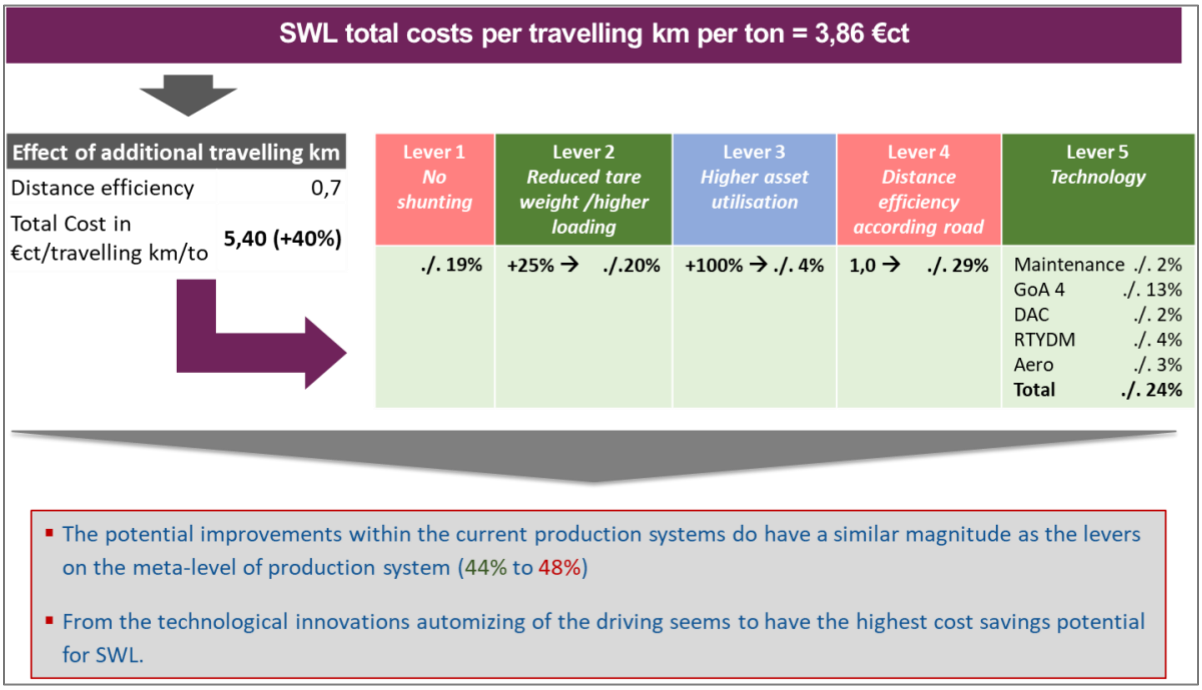


Figure 17: Study – Influencing specific cost of transport for SWL-Traffic

It can be clearly seen that four of the five levers have a similarly large potential for reducing transport costs. It is in the range of 20 to 30 % compared to today's average values for single wagonload transport. The dominance of technological, i.e. process-side improvements is striking. Eliminating entire processes and seeking cost competition with road on those routes where the rail infrastructure is geographically well positioned, but bundling more transport volumes in one train has the greater effects.

With lever no. 3, on the other hand, the effect is an order of magnitude lower. This could also be expected because the discussion of the parameter acquisition costs for wagons in the previous chapter had already shown that its influence is significantly lower than is generally assumed. A doubling of the mileage has an analogous effect on the total costs via depreciation as reduced acquisition costs.

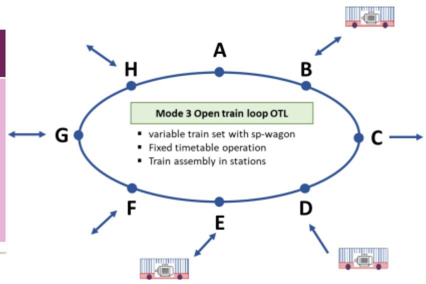
Lever no. 5 summarises five technical measures, of which automatic driverless operation (GoA 4) has the greatest effect. All other measures are in the range of a few percentage points. This shows that technical improvements have to be considered holistically and that a significant improvement in the economic competitiveness of rail can only be achieved by combining different measures.

The large economic effect shown with lever no. 1, in which it is first theoretically assumed that no train formation in shunting facilities is required in single-wagon traffic, will be further investigated in the following. In FR8Rail, the production method proposed for wagon-based logistics on rail was OTL and semi-autonomous freight wagons. This does not require train formation facilities and can be realised with the shunting areas in stations. The figure below shows the result of the cost simulation of such a procedure compared to today's single wagon traffic.

Wagon load traffic OTL-Mode

Input parameter SWL reference

60.000 km per wagon / 18 wagons
713 to. payload
434 m train length
1127 to. gross weight train
600 km travelling distance
Distance efficiency 80%



Input parameter CFW-Concept for OTL operations

18 wagons with drive unit/locomotive
Wagon 200.000 €, 20 years life-time
Variable train length, average 16 wagons
Max. payload 1200 to
600 km travelling = transport distance

Cost in €ct/travelling km/to	SWL
Loco Costs	0,33
Wagon Costs	0,45
Yard Costs	0,75
Loading/siding Costs	0,49
Energy Costs	0,34
Train Driver Costs	0,50
Infrastructure Costs	0,90
CCS Costs	0,09
Costs of delay	0,02
Total	**3,86**
Total travel. Efficiency	**4,83**

./. 64%

Cost €ct/distance km/to	OTL
Loco Costs	0,16
Wagon Costs	0,35
Re-configuration Costs	0,07
Loading/siding Costs	0,24
Energy Costs	0,21
Train Driver Costs	0,13
Infrastructure Costs	0,52
CCS Costs	0,05
Costs of delay	0,00
Total	**1,74**

Figure 18: Study – Impact of OTL-Concept on cost of transport compared to SWL

For the same transport distance of 600 km, this concept can reduce costs by 2/3 compared to the reference SWL. About half of the cost reduction is due to the higher distance efficiency. It can be assumed that decentralised train formation with OTL can take place in any station and is not dependent on train formation facilities. Relative to today's single-wagon transport, the distance efficiency can therefore be assumed to be 1.

This must be considered in more detail in the comparison with road transport. Depending on the specific transport relation, there may still be a disadvantage of rail compared to road. However, this is then significantly less than with the current SWL production method, because only the difference in the distance over the rail network compared to the road can influence the distance efficiency. However, the location of the few train formation facilities then no longer has any influence. This result also speaks in favour of thinking through the entire system and not being satisfied with the current system and selectively conceivable improvements and optimisations.

The comparison to a partial automation of the shunting operation, which was given in the sensitivity analysis for single wagon traffic above [see Figure 18] with 4 % (real-time yard management), speaks a clear language and should give a clear indication that it is not the lower degree of automation of the train formation, but this process itself that is a problem. And this not only on the cost side, but also in the transport time and reaction time of the rail system.

7.2.4 Parameter Study for Intermodal Traffic with Impact of P2P and CTL Mode

The most attractive market segments for growth in rail freight transport were identified in Shift2Rail as well as in other research programmes in the area of LDHV goods.[58] However, these markets can only be addressed by rail with intermodal concepts due to the goods flows being distributed over a large area. In the research result of FR8Rail, it was suggested to concentrate on scheduled transports with the production methods P2P and CTL and to increasingly enter the competition to road with this cheap and reliable service offer.

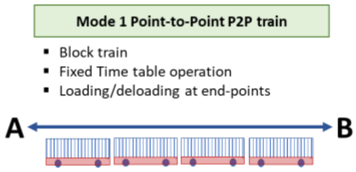
The simulation of these production concepts with the cost model used here from the Shift2Rail's IMPACT projects (ref. IMPACT-2, cross cutting activities) revealed an extraordinarily high potential. This also underlines once again that the performance of rail freight transport and its future prospects do not depend on individual measures or specific technical innovations but are a question of the overall system. This needs to be reconsidered and the sector needs to set itself up structurally accordingly.

[58] SPECTRUM D1.3, FR8RAIL D1.1

Intermodal traffic P2P-Mode

Input parameter CT reference

90.000 km per wagon
13 wagons with 26 platforms
499 to. payload
464 m train length
979 to. gross weight train
600 km travelling distance



Input parameter CFW-Concept for P2P operations

200.000 km per wagon, 20 years life-time
25 double-unit wagon
750 m train length
Max. payload 1200 to
600 km travelling distance
Loading factor 85% in to, 90% in units

Cost €/travelling km/to	Combined traffic train
Loco Costs	0,27
Wagon Costs	0,36
Yard Costs	0,00
Terminal Costs	0,42
Energy Costs	0,33
Train Driver Costs	0,52
Infrastructure Costs	1,03
CCS Costs	0,10
Costs of delay	0,02
Total	**3,06**

Cost €ct/travelling km/platform 45'	Combined traffic train
Loco Costs	6,34
Wagon Costs	8,49
Yard Costs	0,00
Terminal Costs	9,77
Energy Costs	7,74
Train Driver Costs	12,30
Infrastructure Costs	24,15
CCS Costs	2,41
Costs of delay	0,56
Total	**71,77**

./. 48%

Cost €ct/travelling km/platform 45'	Combined traffic train
Loco Costs	2,46
Wagon Costs	5,65
Yard Costs	0,00
Terminal Costs	8,16
Energy Costs	6,18
Train Driver Costs	2,13
Infrastructure Costs	11,42
CCS Costs	1,14
Costs of delay	0,08
Total	**37,22**

Figure 19: Simulation of Unit Cost in P2P mode compared with Combined traffic CT today

Specifically, under the assumptions made for train operation and its marketing, a cost reduction of almost 50% can be achieved in both modes considered. [Figures]

For this calculation, as already discussed in Chapter 3, the costs in tkm from the cost model were converted into costs per container-km (unit-km) and the characteristics of the respective production concept, including its other operational and technical characteristics, were incorporated. With this production concept, the dominant costs for transport are the costs of using the infrastructure (train path charges and terminal costs) and energy. The costs of the vehicles (rolling stock), on the other hand, account for a good 20 %. The costs of the train driver, on the other hand, do not play a role in terms of costs, although automation of the train journey was not even included. This is because the timetable-based production concept on the one hand and the utilisation of the maximum train length on the other more than halve the need for train drivers for the same transport volume.

Regarding road charging, it should be mentioned that the cost of rail in the EU can easily be reduced below the cost rate of road if it is used efficiently. The costs on which the cost model is based correspond to those of a high-wage country such as Germany and fluctuate within the EU due to the different factor costs. The assumed reference train of the cost model as an average intermodal train is therefore on a train path with approx. 5 €/km train path charge with 24.15 €ct/unit-km above the road user charge in 2019 with 15 €ct/km and truck, whereby this parameter is currently fixed and therefore very much subject to degression. In the P2P production concept, this value is also significantly lower at 11.42 €ct/unit-km.

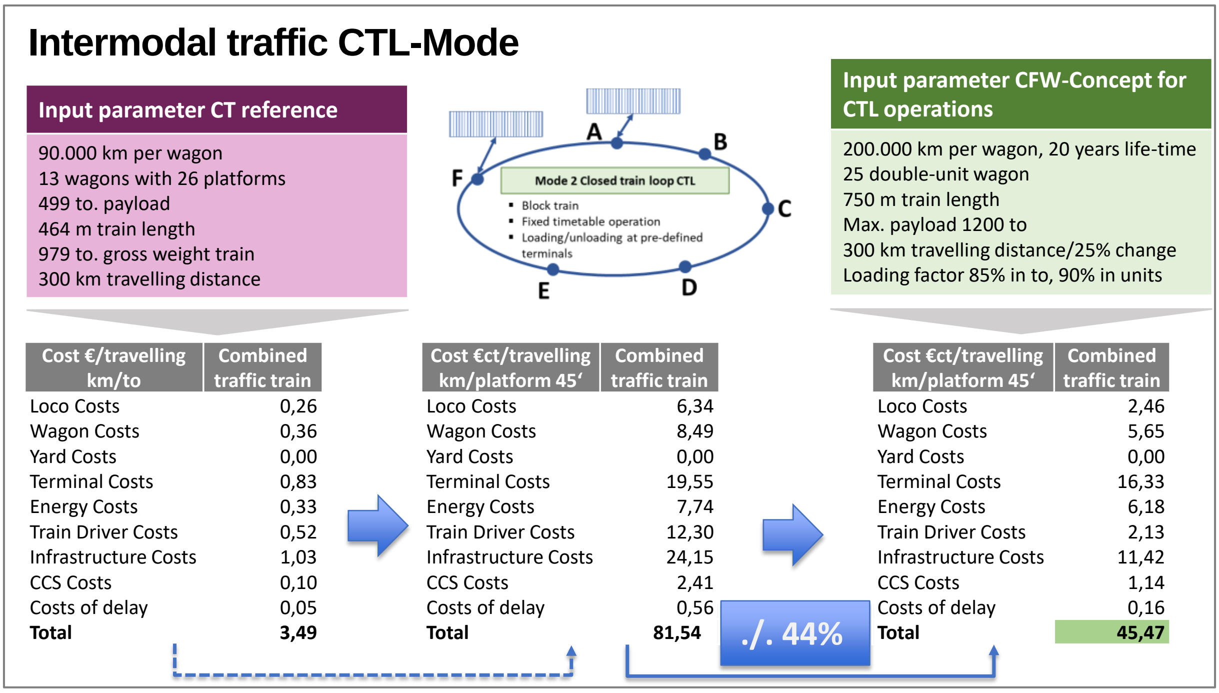


Figure 20: Simulation of Unit Cost in CTL mode compared with Combined traffic CT today

For the production method CTL, which essentially differs from P2P in that intermediate stops with loading changes are foreseen, it is above all significant that the use of rail can be economically interesting for a transport distance of 300 km, despite the loading change from road and back twice. The 300 km correspond to the assumption of the EU White Paper. There it is assumed that the modal split can only be changed in favour of rail in an economically sensible way above a transport distance of 300 km because of the basic costs for changing the load. The figure shows that the transport costs of rail with CTL are significantly lower than the costs of road, which amount to 119 €ct/unit-km on average. This also applies to the reference train of the current system, for which costs of 81.54 €ct/unit-km were calculated.

7.2.5 Assessment of Future Competitiveness of Rail Freight

In this chapter, the cost model that was developed in Shift2Rail in order to be able to evaluate the impact of the innovations was used to carry out parameter studies with individual aspects, but above all with the overall system. For this purpose, the reference transports were used and the effect of the production processes with the associated characteristics was simulated. In the process, considerable cost reduction potentials could be identified.

In view of the initial situation of rail freight transport and the expected further development of road transport logistics, these are also urgently expected. Road already dominates land transport today, although it has higher costs. The reason for this lies in its flexibility and speed compared to the stagnant and ossified system of rail freight transport. As soon as the road succeeds in significantly reducing costs through automation and platooning, and the road thus reaches or even undercuts the current transport costs of rail, there is little to suggest that there can still be any rail freight transport at all in the future under market-economy conditions. If the problem of rigid driving time regimes is solved by the automatic operation of trucks, road freight transport in Europe will be able to take over today's rail freight transport at any time. On the other hand, this is not the case on the railways. Even the growth of about 100 % by 2050 desired according to the EU White Paper [Ref. D1.2 FR8Rail] far overtaxes today's rail freight system. Without dramatically improved logistics concepts and production processes, the capacity of the rail infrastructure is not sufficient for such growth. However, a significant expansion of the rail infrastructure without more efficient production processes makes no economic sense, as it destroys value instead of creating value. Production processes are thus the linchpin behind the considerations of the EU White Paper. This is where the future of rail freight transport will be decided.

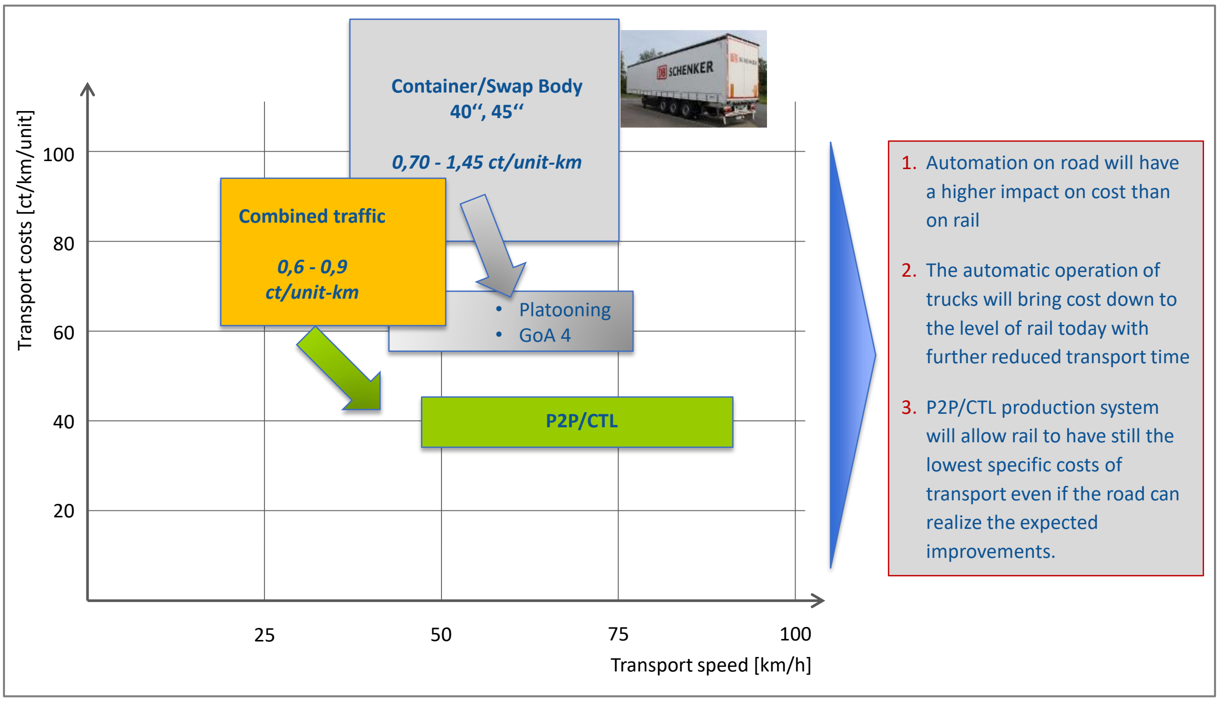


Figure 21: Competitive matrix for transport systems for containers/swap bodies

The Figure 21 above summarises the competitive parameters of costs and time for freight transport in a portfolio representation, shows the current competitive positioning of road and rail using the example of container transport. In addition, an outlook is entered for road, in which the effects of automation and platooning on energy costs were anticipated. For rail, the potential shown in the cost simulation was entered. It can be seen that rail can maintain the relative cost gap to road with P2P and CTL in intermodal transport in the future. In addition, rail gains in speed with the procedures, which is essentially due to the timetable-based and efficient implementation with fast trains. This assumption bases on the recognitions from chapter 7.1.

Such a representation can also be used for single wagonload traffic in order to get a clear picture of the starting position, the future threat and suitable measures to meet it and expand it for rail freight. (see Figure 22)

The starting position today is already less favourable than in combined transport, because with a high utilisation of the possible payload of the truck, this is already in the range of the transport costs of rail. This explains, for example, why more and more chemical transport has been handled by road in the last decade. Without a new approach to wagonload transport, such as the one proposed here, there is little hope for rail to even be able to maintain its market share in the future.

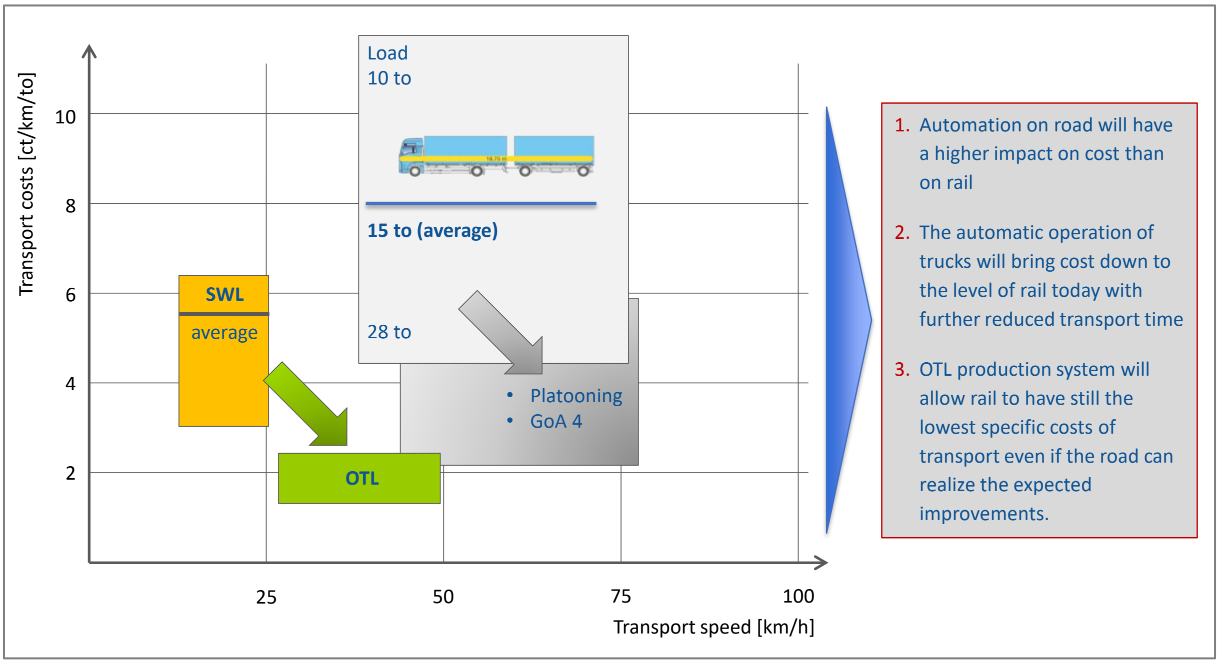


Figure 22: Competitive matrix for transport systems for single wagon load transport

7.2.6 First Conclusions

In chapter 7.2, the results of the parameter study with the cost model for rail freight transport were explained and an attempt was made to place them in the competitive context. It could be shown that the rail transport system can be further developed in such a way that the competitive situation to be expected in the future can also be met with significantly lower transport costs on the road and that the rail freight transport system can in principle be in a position to attract additional market shares in the transport market.

However, individual isolated measures and improvements to the existing freight transport system, which has developed historically, are not sufficient for this. What is needed is an unbiased consideration of the opportunities and possibilities of rail, which in its core as a track-bound transport system for the transport of masses (large volumes) is subject to certain restrictions that preclude competition on a broad front with road. Rail can only be successful where it succeeds in bundling transport volumes quickly and efficiently on a route. Depending on the type of transport and cargo, this requires different production concepts, which were considered in Shift2Rail [Reference FR8Rail]. The simulation results show that these concepts with the associated measures for automation and increased efficiency are suitable for significantly improving competitiveness. The production concepts are all based on fixed timetables that provide planning security for all parties involved. The art is then to use very good market knowledge to make the right transport offer for the attractive routes and then to implement this consistently in sales.

Any other approach (with implementation of individual technologies, implementation of isolated individual measures) only leads to suboptimal improvements that will not be sufficient to effectively take market share away from road.

8 Migration as a complex process for rail freight

8.1 Rational of Migration

The research activities in IP5 are diverse and cover all technical assets that are required for sustainable rail freight transport. This includes the vehicle technology of locomotives and freight wagons as well as infrastructure facilities.

The portfolio of IP5 consists of innovations of different scope, which can be characterized as either **evolutionary**, **bridging** or **revolutionary** in relation to the current freight rail system in Europe.

Therefore, the developed solutions as the technical outcome of IP 5 vary regarding:

- the potential of substitution of the current system
- the investment scope and volume (capex in infrastructure and/or rolling stock)
- the need for financial public support (subsidies) and the
- the degree of compatibility to the current system and its components.

(see Figure 23).

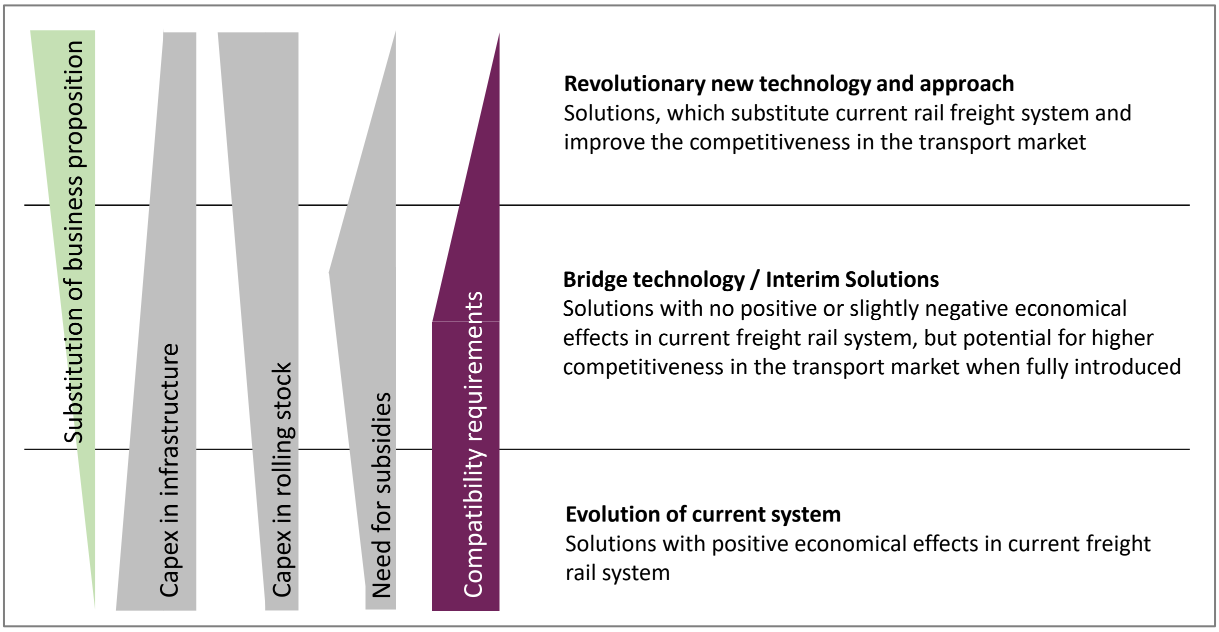


Figure 23. Rational of Migration

The need for subsidies seems to be a must have for bridging technologies as their benefit cannot be realized with the current systems due to remaining boundaries and/or at least not during the migration phase as the full potential requires a completed roll-out of the technology.

The evolution of the current freight system, which will get production of transport better done. Thus, this approach will contribute values to the freight rail system, especially on the short- and mid-term perspective. Although, this will not be enough to become competitive against road transport, these innovations should take place to strengthen freight rail transport in the transition phase from the current freight rail system to the “production system for the future for freight rail transport”. The financially big advantage of the evolution is the lower need for subsidies as the measures will mainly have a short payback time.

Finally, the revolutionary approaches do not depend that much on subsidies because this approach intends to implement a new freight rail system in parallel to the existing one with a different functional distribution between infrastructure and rolling material and – more decisive – a different perspective of the transport market. It is not the question: how we can do better within the boundaries of the current system is the guideline; the only criterion is how the rail system can become competitive to the modern road transport again. Different from the other approaches the revolutionary approach cannot be mixed with the current operational modes as the meaning will not be compatible anymore. The introduction must follow a separate path should therefore start with block train operations in a homogeneous train set.

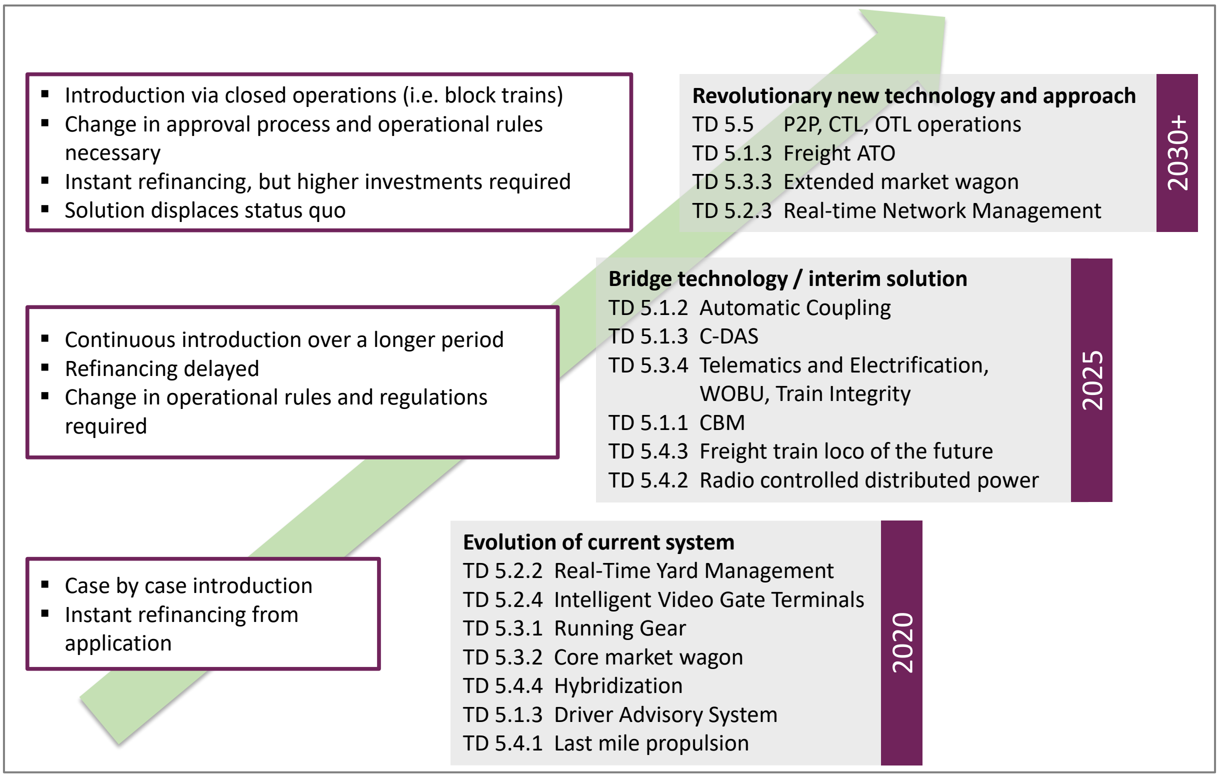


Figure 24. Application of migration rational to IP5 activities

8.2 Innovation Portfolio and Logical Order

The IP-Portfolio comprehends seven core technical solutions supported by and partly depend of 10 technologies on sub-system level (see Figure 25):

- Automated freight train
- Autonomous wagon for SWL
- Freight train loco of the future
- Extend market wagon
- Core market wagon
- Real-time network management
- Real-time terminal management
- Intelligent video gate terminal

and the operational modes for a highly efficient production system of freight rail in the future (FR8RAIL D1.2). The benefits for the forwarder will be driven by these core technologies.

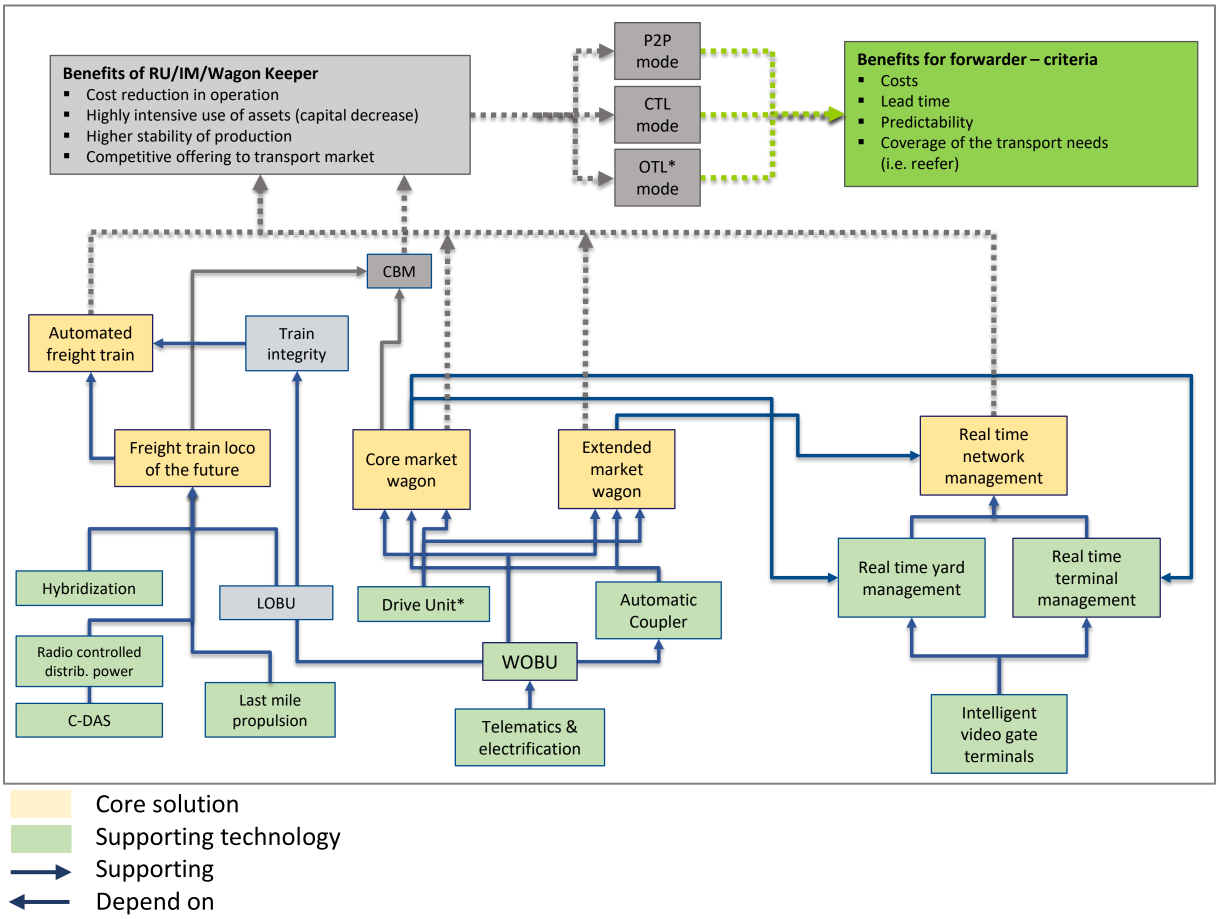


Figure 25. Interdependencies of the 5 core innovations areas and the 10 supporting technologies

It should be noted that the supporting solutions have different relevance for the respective operating modes and wagon solutions. For example, marshalling yards for point-to-point connections (P2P) and the Closed Train Loop (CTL) with the Extended Market Wagon (EMW) are not relevant, as the train configurations (except for locomotive) are intended to be fix in these modes. Thus, the lengthy processes associated with shunting and train formation are eliminated in the production scheme of P2P and CTL. That means various advantages: The lead time in relation to the total transport time is significantly reduced, the costs for the train formation processes along the transport route are also eliminated and the logistics chain gains in reliability.

As a second example for the different relevance of a supporting technology the automatic coupler can serve. It is primarily relevant for the CMW, because this concept is essentially characterised by single wagon load traffic and Block train operations with reconfiguration of the trains at the destinations and must therefore be compatible with the existing UIC system. The situation is different with the EMW. Here, the automatic central buffer coupling plays only a minor, since the compatibility requirements only apply to the end wagons – so, the connection with the locomotive. Within the wagon arrangement, there are no requirements at all for compatibility with the existing UIC-based fleet. This also has important advantages: Additional investment in coupling technology is not necessary. The scope for innovation for the wagon solutions is considerably greater, since the compatibility of the wagons is only relevant for locomotives and no longer between different wagon types. This also makes it much easier to migrate wagons/technologies when there are changes in the fleet, as only connected wagon types are affected. The Safe Train Integrity-system (STI) is much easier to implement than in heterogeneous train systems.

No decentralized power supply and telematics solution required, because communication and management can be implemented via the locomotive as a master and enables also proprietary solutions.

In other words, wherever compatibility with the existing system is required or is to be maintained, the benefit will only unfold once the entire fleet has been replaced or the existing fleet has been brought up to date by retrofit measures. In the case of breaks in the equipment status within a train, the investment clearly exceeds the benefit.

In addition to difficult investment decisions in interim solutions with no noticeable increase in benefits, the availability of individual solutions plays a particularly important role on the time axis, as they are sometimes a prerequisite for supporting solutions, e.g. the automatic coupling is an enabler for the complete electrification of wagons which operate in single wagon load. Only then can telematics applications and the WOBU be implemented.

8.3 Transformation of the Production System

The intended positive development of rail freight transport in Europe depends on its transformation into an integral part of land transport logistics chains. In this process, rail must take on the role in which it can effectively contribute its strengths as a means of mass transport. This point has been made several times in the previous chapters. The dramatic increase in competitiveness in terms of flexibility, responsiveness, transport capacity and costs can only be achieved by changing the range of services. Production processes play the decisive role in this. The P2P, CTL and OTL processes proposed in FR8Rail cover the entire range of transport that can be reasonably served by rail. The current procedures, which consider the freight wagon as a disposable variable, can be replaced by the new system. The decisive criterion here is whether the transport can be containerised or not. If yes, the traffic can be served efficiently with the P2P or the CTL procedure. If not, the OTL production method with semi-autonomous wagons allows efficient production without having to rely on dedicated large train formation facilities. Figure 26 schematically shows the transformation of today's production processes to those of the future.

Of course, this transformation will not happen in the short term, nor can it be centrally administered. Technocratic approaches in complex economies never lead to an optimal solution because the necessary information is not available and processes and actors interact in a non-linear way. However, the transformation can and must be initiated and meet the right framework conditions so that it grows into a self-reinforcing process.

Since containerised transport has the greatest growth potential, it should start with P2P and CTL production methods on selected routes. Next, existing terminals may be expanded and optimised according to the flow-through principle, and then new terminals may be built. For all these services, there are no or only few compatibility requirements, because the trains operate in a fixed configuration and even in the case of partial dismantling with an unfavourable terminal layout, a fixed assignment between locomotive and wagons remains. This dramatically lowers the barriers to innovation and leaves the rest of the traffic in the UIC system untouched. Only gradually will this conventional traffic be displaced, and this will be done by the players in the sector themselves, because the market success of the new one will provide a high economic incentive. Providers who are the first to understand this and know how to use it will profit from this decentralised market-based process. The others will lose importance and eventually be squeezed out.

The state only has to make sure that deregulation and privatisation create the conditions for the described transformation. It must concentrate its investment resources on the infrastructure and there on the elements that promote the transformation process and not on the elements of the old world. In concrete terms, this means investing in terminals and in the track facilities on the routes where transport volumes can be bundled in the main run. This also includes transhipment stations with distribution and sorting centres directly in the conurbations and city centres to allow rail freight to once again have direct access to the centres.

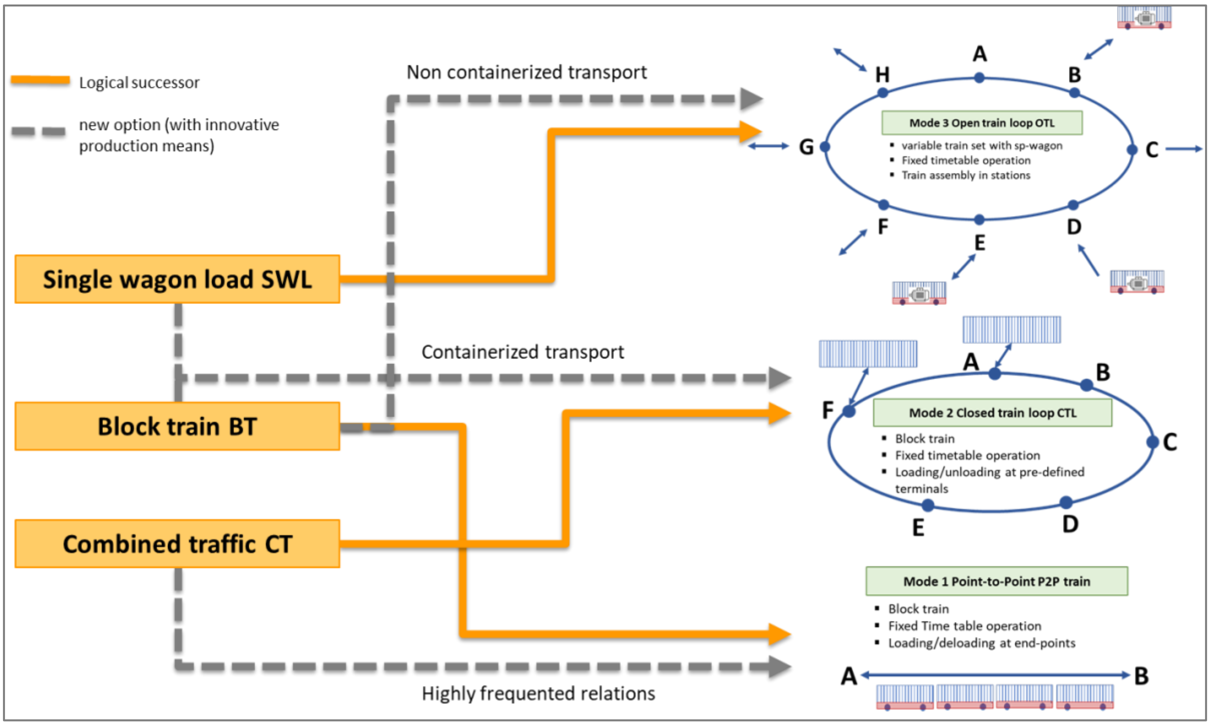


Figure 26. Transformation of UIC Production Modes to competitive FR8RAIL

Finally, a comment on the production concept with semi-autonomous wagons OTL. The basic idea is in principle the further developed single wagon load traffic, in which, however, the train formation takes place decentrally in any stations - assuming sufficient track lengths and track changing possibilities. A marshalling yard with train formation as it is understood today is then no longer needed, as described in chapter 4.4. The application for this can naturally only be provided by those transports where a specific structure is required and containerisation is out of the question. However, these do not represent attractive growth potentials for rail. Here it is more likely a question of rail retaining its strong position in certain market areas, but becoming faster, more flexible and more efficient. OTL will therefore be able to play a role in future rail freight transport, but not a dominant one.

8.4 Stakeholders View on the Benefits of Innovations

The technical innovations that Shift2Rail is pushing forward in rail freight transport are primarily intended to improve the higher efficiency of the system. They are necessary and sensible, but are they also sufficient for rail freight to take on the desired greater role in the land transport of goods? This question can only be answered from the perspective of current and potential new customers.

Starting from the realisation of a generally better cost position of rail compared to road, this leads to the evaluation of technical innovations on the other success factors in the transport market.

As the studies in Smart Rail and Spectrum have shown, the following criticism is voiced by freight forwarders and transport customers:

- Mind-set of the rail sector: Focus on timetable and train operations instead of supply chain orientation.
- Transparency: No digital workflow from end-to-end. Shippers and Forwarders and their customer do not get the right status of the transport in time.
- Flexibility and responsiveness: The adaptability of the production system to incidents in operation and change in customer demand is not part of its design.

To assess the potential for a modal shift from road to railway transport, Spectrum revealed, it is necessary to know which criteria could be decisive for logistics decision-makers, when they are considering alternative transport options. The so-called modal choice is mainly based upon costs and service levels. In all, the decision between road (and other modes) and railway transport depends on:

- The overall existence of a modal choice on the transport route requested.
- The level of transport costs (main course haulage plus pre- and on-carriage plus eventually additional costs for transport equipment).
- The level of costs for transhipment for switching between modes (namely intermodal load transfer from road to rail and vice versa).
- The level of transaction costs (costs of gathering information on the transport options, costs of establishing a business partnership, costs of checking the business partners…) compared.
- The level of service quality (transit time/lead time/speed, transport reliability, delivery accuracy/quality, flexibility, readiness of information).
- The costs of adapting the system (opportunity costs or sunk costs e.g. for unused capacities like trucks, locked-in effects e.g. when investing in intermodal equipment).
- **Lack of experience and expertise with certain transport modes.**
- **Risk aversion in the rail sector.**
- **Poor perception of rail's capabilities and a belief that rail is only of interest in long haul corridors with large train formations**.

It is certain that there are trade-off relationships between the factors above identified by Spectrum. For instance, even if transport plus handling costs are lower in intermodal transport than in road transport (see also chapter 7.2), the perceived poor level of service of the intermodal transport may deter a shipper from using intermodal services. Also, the service performance of intermodal transport has to reach a certain degree, to persuade a reluctant shipper to consider the intermodal option in more detail.

An essential requirement is the overall existence of modal choice, which must be perceptible to the logistical deciders. The difficulty of finding accurate information on services, schedules, space availability, pricing and tracking are key indictments against rail. Service reliability, above all reflecting the degree of punctuality, is the outstanding service criterion, and in some cases, even more important than the price.[59]

In a nutshell, the railway system is complex from the customer's point of view, has many actors and in the end is not very transparent for the transport customer. The flow of information is not comprehensive and often not reliable.

If you look at the technical portfolio of Shift2Rail from this perspective, the innovation elements "real-time network management" and "telematics applications" are particularly striking, because both can be used to increase transparency in the system and forecast quality. If logistics-relevant information is made available to customers in the usual formats of logistics data processing via appropriate interfaces, then the customer can have the current transport status and forecast for arrival at the destination in real time. This corresponds to what they are used to from road freight transport and is state of the art there. In this respect, these two technical innovations from Figure CC are of particular importance for transport customers. Consequently, the collection and integration of rail logistics data into the higher-level logistics systems is important.

With regard to the usability of the rail freight transport system by freight forwarders or carriers on the road, it is of particular importance whether there are stable transport offers that can be accessed quickly and easily. From its function as a means of mass transport, rail must bundle traffic, i.e. transport orders. The simplest way to do this is to offer services based on fixed timetables that are made available to customers in a transparent way via internet applications. The solutions contributed by Shift2Rail for this are the production concepts P2P, CTL and OTL, which are all based on fixed timetable-based transports.

8.5 An economical Investigation of Capital Need for Migration

The migration, i.e. the transformation of the current rail freight system into an efficient and competitive element of the land-based transport system, must take place under strong financial pressure. The overall lack of competitiveness together with the low overall profitability does not allow a net increase of capital investments.

The past decade with its dramatically downfall of interest rates has been used by private investors in the rail freight sector (wagon keepers, operators) to optimise the capital structure in their balance sheet. This has allowed to reduce the overall expectations of the return of investment from 12 to 15 % below 10 % today. But, this lower expectations did not lead to a higher competitiveness of freight rail business in general as the road transport segment has used the downfall of the interest rate by themselves – moreover the sector has invested in assets with lower operational cost, so that the distance between road and rail in terms of competitiveness could not be reduced.

Looking with a broader view on the state-owned railway undertaking companies in freight the financial picture of the freight sector becomes even more de-illusionary. All these companies do not earn money on their total business. More capital will not improve this situation as the depreciation must be earned from operations and the interest rate is just near zero.

Therefore, the assumption is that the freight rail sector must stay with the current capital exposure and should try to optimise the use of the free cash from depreciation to transform the rail system.

[59] SPECTRUM, D1.3, p. 31/32

The higher productivity and utilisation of the mobile assets with the operational modes proposed in FR8RAIL imply a complete change of the mobile assets within the next 2 decades.

The total expenses in retrofitting the current assets will be lower as only a limited quantity needs to be invested compared with the current fleet. For the retrofit measures in the UIC context, this would mean the following:

Wagon	Costs per Wagon
Automatic Coupling Type 5	16.000 €
WOBU	10.000 €
Electrification	5.000 €
Total	***31.000 €***

Locomotive	Costs per Loco
Automatic Coupling	20.000 €
LOBU	50.000 €
Total	***70.000 €***

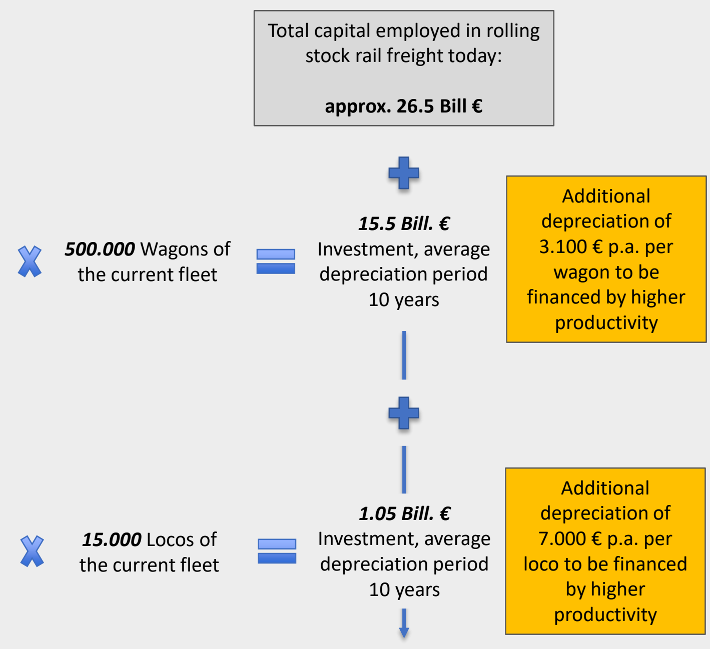


Figure 27. Retrofit capital expenditure – wagons and locomotives

The capital exposure in rolling stock for freight within the EU can be estimated to be approximately 25 billion €, if an average book value for the current fleet of wagons and locomotives is assumed under the fact, that the average age of these assets is comparably old (see Figure 28). The task of transforming the freight rail sector means in this perspective to change the real assets behind the values in the balance sheet without increasing the total capital.

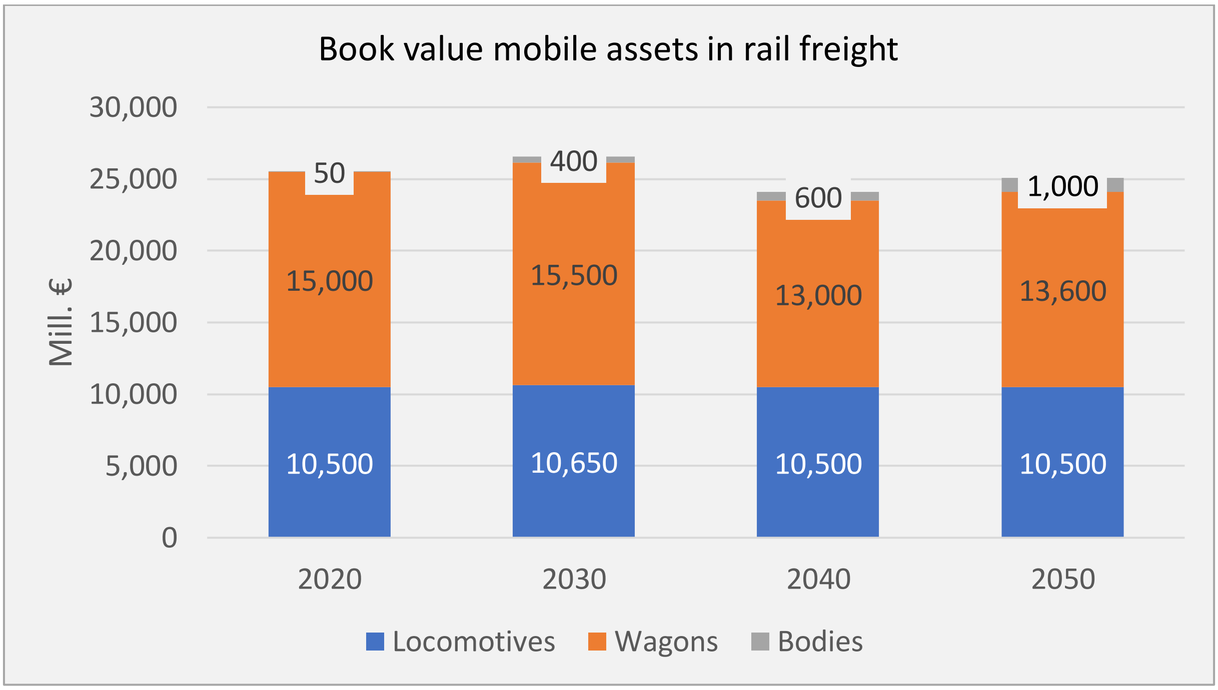


Figure 28. Stable book values for mobile assets rail freight

Due to the far higher productivity of the new operational modes (see Figure 29 and Figure 30) and the appropriate technology the total capital need in the European railway sector will not increase although the projected transport performance in 2050 is about double as high as in 2015 (EU White book). It will remain around 25 billion €.

The depreciation of old assets and its replacement with a lower number of assets can finance the transformation of the system on the side of mobility assets. Assumed that the current assets can be fully written down within 20 years - which is a conservative assumption regarding the age of the fleets – 25 billion € for investing in the future would be accessible, which means 1,25 billion € p.a.

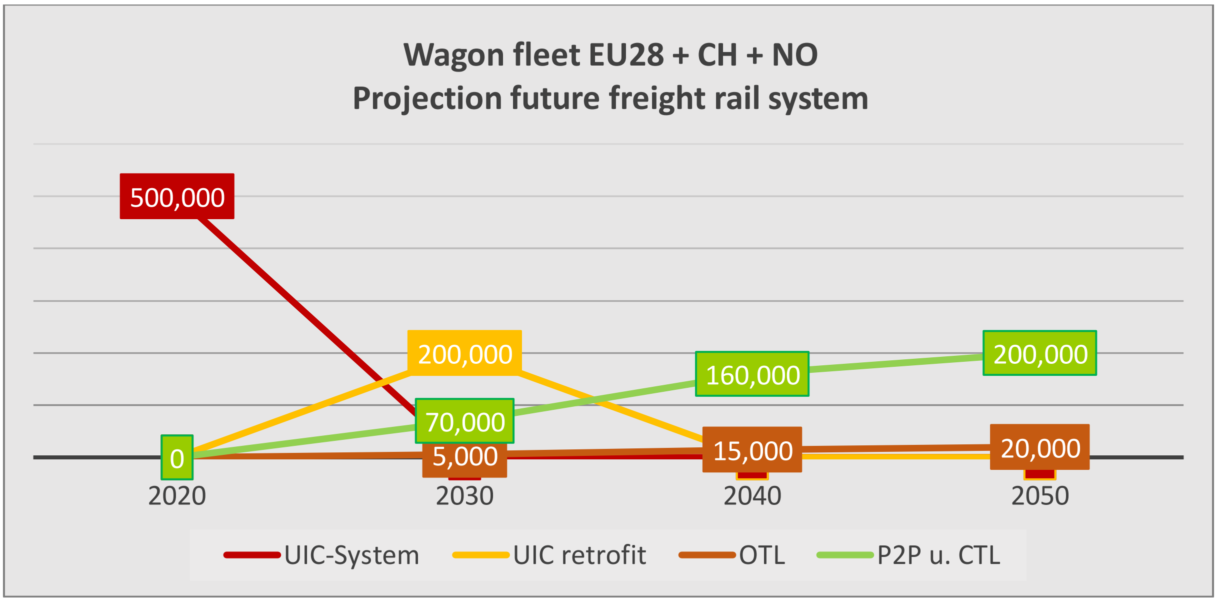


Figure 29. Wagon fleet composition until 2050

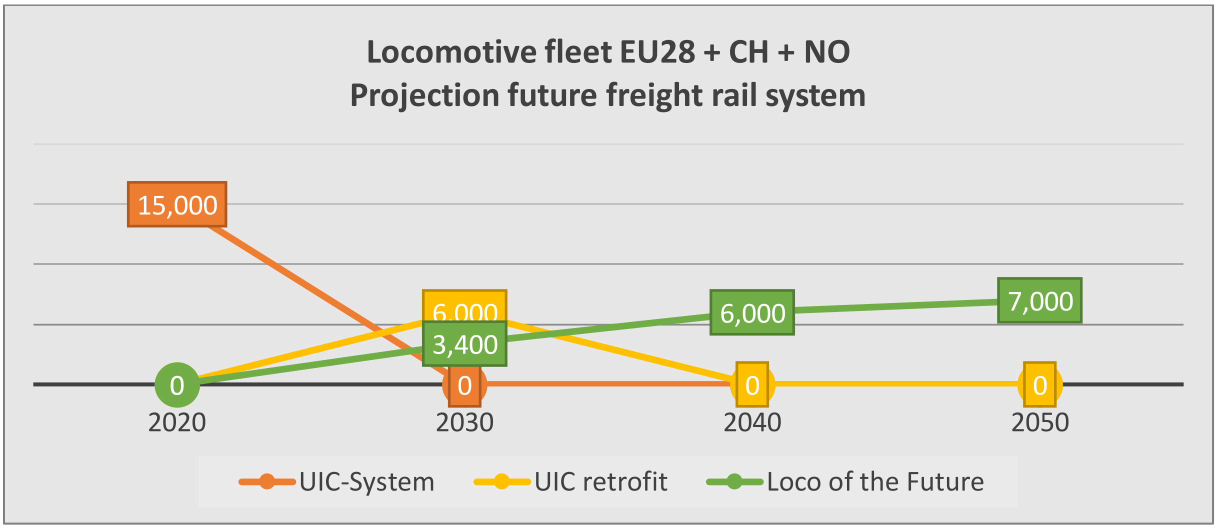


Figure 30. Locomotive fleet composition until to 2050

8.6 Sector Organisation and Solidification

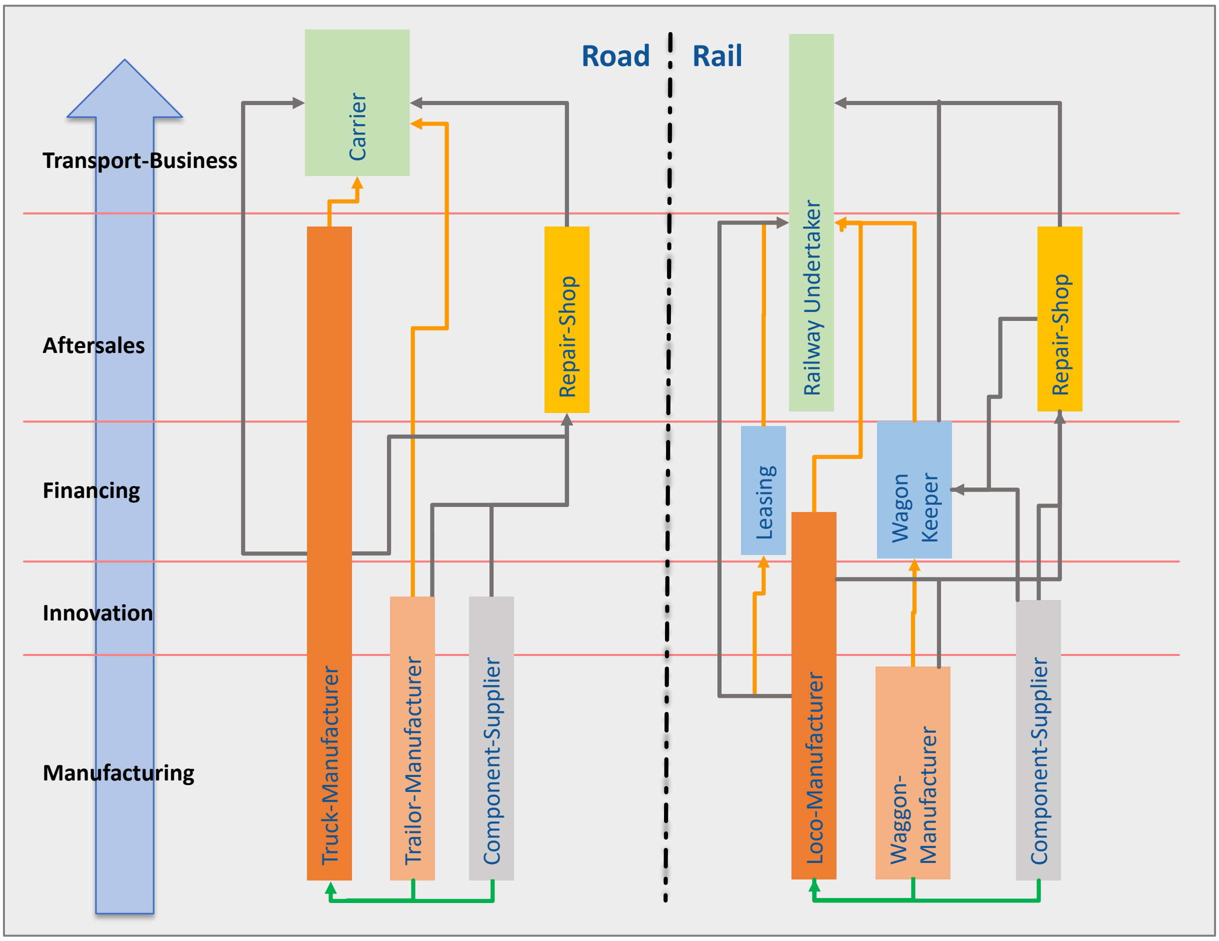


Figure 31: Structure of net value added in the sector

The rail freight sector has some notable structural differences compared to road freight. The main investment for road is in the truck. The truck manufacturer controls the entire value chain from manufacturing, marketing, financing to aftersales. He himself provides a substantial scope of services and covers about 80 % of the gross value added in the above-mentioned stages. For the trailer, the statement is true to a lesser extent, since the financing is taken over by banks or leasing companies. Also, the gross value added is lower due to the strong market position of some component suppliers, but the margin is still large enough that innovations can be financed and self-designed. The majority of independent workshops are tied to OEM manufacturers. The buyer of the vehicles is the transport operator, who handles the transport as part of the higher-level logistics process and has to bear the resulting costs of operation and maintenance.

On the rail side, on the other hand, we find an entirely different structure. The counterpart to the road manufacturers does not exist in that form. Wagon construction today is essentially a contract manufacturing of UIC solutions with non-protected predefined components that have been produced for decades. The gross value added cannot be controlled by wagon construction.

The locomotive manufacturer has been able to emancipate itself from the (former) state railways in the last three decades with the start of the privatisation processes in the railway sector. Nevertheless, his position is not comparable to that in the automotive sector because the railway undertakings and the infrastructure companies still exert a very strong influence on the specification of the vehicles directly or even only indirectly via the UIC system. Furthermore, there is no service network of the manufacturers with their own or contracted workshops. Maintenance is carried out in the operations of the railway undertaking.

Unlike on the road, there are other players. These are, on the one hand, the wagon keepers, who can also be identical with a railway undertaking and carry out or have carried out the maintenance of the wagons via their own or external workshops. Or the wagon keepers are purely geared to hiring out the wagons, in which case there is also the case with their own workshops. In essence, however, the wagon keepers are lessors and thus belong to the financing side. In principle, this is a debt-financed leasing business.

On the transport side, there are differences to the road. In addition to the operator, the traction provider may also be required to process a transport order. In this case, the transport business breaks down into two parts. In addition, on the infrastructure side, further players are involved in train formation, delivery, filling/loading, which take into account the more complex operating procedures in today's production processes and have arisen historically.

This leads to a much more complex distribution of value added, in which the individual levels and contributions of the service providers build on each other and are linked to each other via the overall system. Its optimisation therefore often requires an overarching approach, which necessitates interventions in the autonomy of the legal entities. To make matters worse, many substantial improvements require a shift of value contributions and capital flows, where in the current structure of the sector positive and negative effects accrue to different parties, as is the case, for example, with the optimisation of wagons and train formation (see Table 3. Tabular presentation of benefitting stakeholders by solution in chapter 6.5).

The benefit accrues to the shipper and carrier or traction provider, but not to the investing party, unless they happen to coincide. This triggers an extraordinarily high degree of inertia on the part of all parties and cements the status quo. The unchanged dominance of state influence also plays a significant role here, as the railway infrastructure is entirely owned by state-owned companies and the operation is essentially determined by them. However, state-owned companies, like all state institutions, focus on administration that preserves or expands the status quo and not on progressive further development of the respective sector in which they operate.

In this context, an observation from the Spectrum project with the handling of new market segments such as e-commerce and the resulting new demands on the transport task is also noteworthy and underlines the rigid structures in rail freight transport: *"E-commerce is a specific technology driven trend that has significant impact on the transport sector and poses additional challenges to the ambition of the rail sector to gain market share in the LDHV-goods. The opportunity to place a buying order on the web from anywhere at any time and the expected delivery times and tracking & tracing transparency capabilities are at odds with the current state of play in rail freight transport. Rail has seriously failed to recognise this and other major structural changes and appears unable or unwilling to move away from an over dependency on large flows of lower value high volume commodities. To reposition itself to become a credible competitor for LDHV traffic and commodity traffic a major structural shift within the industry is needed."*[60]

8.7 Conclusion and strategical Imperative for Migration

The explanations in chapter 8 show that the migration of the rail sector, if it is to have the goal of achieving the EU White Paper scenario on increased competitiveness, requires a holistic approach.

Individual steps are nevertheless conceivable, but do not lead to the necessary improvement. In addition to technical innovations, the technological transformation of the transport offer and the organisation of the sector are the indispensable further lines of action.

All in all, it is about nothing less than the transformation of the entire sector. Basically, this was to be expected, since the process of displacement of rail in freight transport that has been observed for decades is essentially the result of innovations in logistics, which road as a less regulated sector has faced up to and in doing so has been able to bring to bear its fundamental advantages in terms of scalability, flexibility and decentralised innovation capacity. The rail freight sector, on the other hand, is essentially frozen in a pre-war order that has been managed but not developed over the past decades.

It follows from this recognition that the great leap forward for the rail transport sector will primarily be a question of organisational change processes, for which there must be suitable framework conditions that suggest to the market participants to consistently use the undoubtedly existing innovation potential of rail and to initiate the changes necessary for this.

This gives rise to the "dilemma of transformation" (see Figure 32). Do we want to pursue an evolutionary approach, which maintains compatibility but is limited in its effect, or do we take a revolutionary approach and deliberately break with the previous system boundaries for greater competitiveness?

[60] SPECTRUM, Deliverable D1.3 Logistics and market analysis – Final Report, p. 26

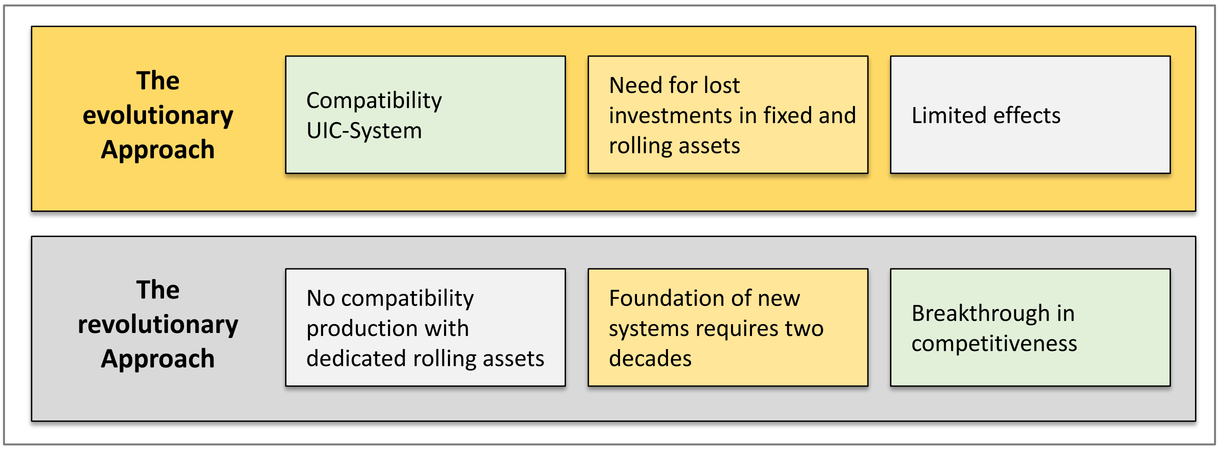


Figure 32. Basic thought on migration of the rail freight system – the dilemma of transformation

Both approaches do not promise a continuous improvement to the intended competitiveness against the road sector. The evolution has limiting boundaries rooting in the UIC production system. The revolution takes too much time to bring improvements on a global basis.

Improving the current system with clear focus and limited application to hold lost investments under control on the one hand and starting the new system with nuclei and having them grown up on the other seems to be the right solution for transforming the sector.

These aspects are examined in more detail in the following chapter.

9 Timeline of Migration

9.1 Basic Aspects for a Shift²Rail and timely Order

The dependencies described in the previous chapter about compatibility with the existing UIC system and about the time of availability of a solution lead to an initial rough classification of the technologies and solution on the time axis (see Figure 33).

With the incremental improvements and upgrades of the CMW, smaller benefits will find quick access to the market. The same goes for the freight train locomotive for the future with introducing new hybridisation concepts, energy storage systems for last mile propulsion and driver advisory systems.

The introduction of the EMW, initially for specific transport tasks and relations, can probably be expected from 2022 onwards. Here, the integration of the WOBU and corresponding telematics applications will lead directly to noticeable benefits in terms of competitiveness. CBM will be comprehensively implemented in relation to an entire train, which will lead to further benefits for the reliability of the rail freight system.

The implementation of real-time network and real-time terminal management should be completed between 2025 and 2030, as the investments in the entire infrastructure are necessary to fully implement the real-time approach. The measures only take effect with the network-wide rollout.

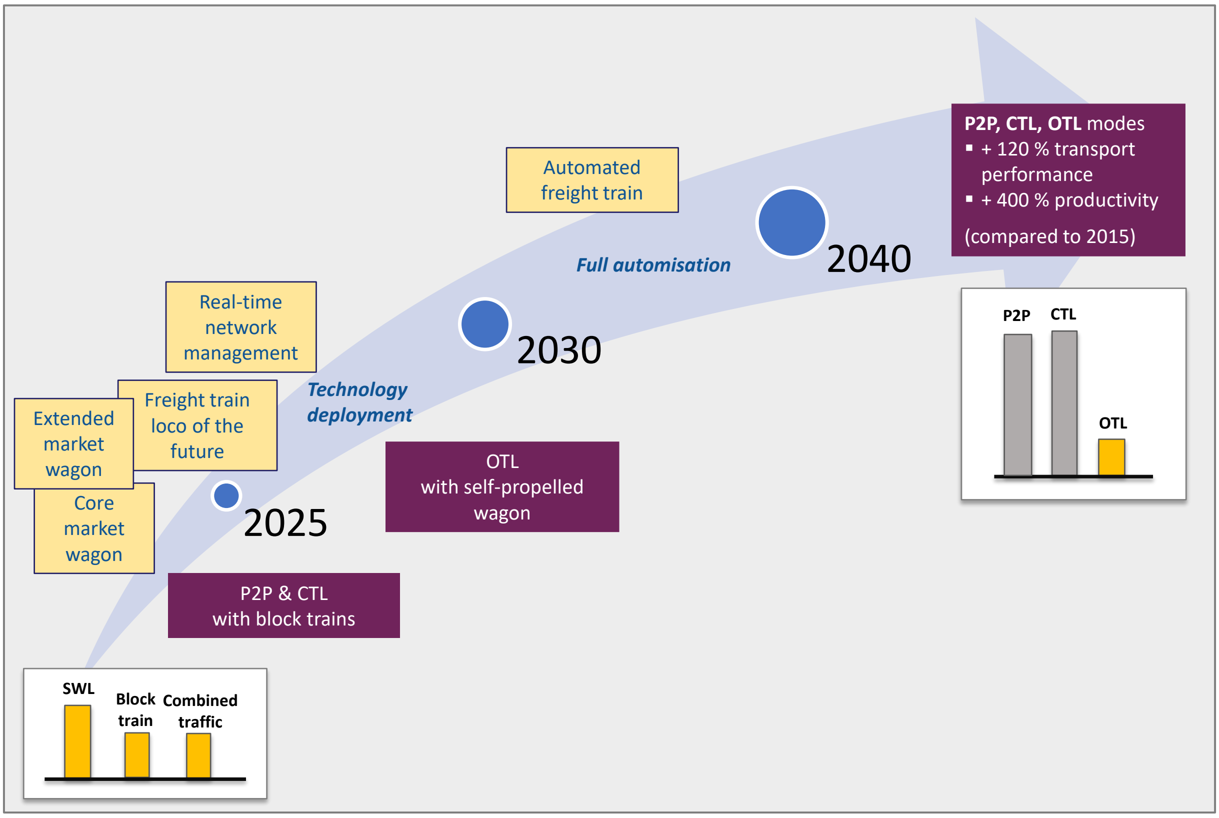


Figure 33. Rough timeline for further development up to the revolutionary step of full automation

Further automation of traffic will not take the next step with the self-propelled wagon until 2030 at the earliest. It will be able to drive independently into sidings. It will also provide the basis for the further development of a highly efficient single wagon transport system. With its technologies, it will be possible to independently divide a train into individual wagons or wagon groups and independently form a new train. The step towards full automation of transport will not take place before 2040.

Until then, preference should be given to applications with closed wagon cycles – P2P or CTL production processes – with which the benefits of new technologies for the train can be exploited to a high degree without the fleets having already been converted sector-wide. Compatibility with the existing fleet is then not given.

Migration should basically follow two paths:

- first, the evolutionary approach - retrofitting the UIC system
- second, the revolutionary approach - creating islands of innovation, focusing solely on competitiveness in land-based transport, high utilization of assets (vehicles and infrastructures), high productivity through optimized process chain – introducing EMW in real block train mode.

According to initial estimates, this will make it possible to achieve even during the migration phase noticeable increases in productivity, as shown in Figure 29 below. While the fleet “melts” down to one half, transport performance in tonne-km doubles (see D1.1 FR8RAIL). This increases the productivity of the fleet by factor 4 at the end of the transformation process.

9.2 Socio-economical Constraints of the Sector

The rail sector is subject to a number of constraints that are worth discussing in order to work out whether they can have an impact on migration.

First, it must be noted that the railways are a highly regulated sector dominated by state institutions. This is the root cause of the sector's pronounced inertia to the point of rigidity, as has been soberly noted in the Spectrum project. Institutions and individuals in this sector, which are protected from the normal market-economy adjustment mechanisms, tend to have a pronounced vested interest, which is also reflected in the demands of the trade unions.

In this initial situation, adjustment processes have to overcome enormously high hurdles. In fact, revolutionary innovations cannot be implemented at all. The innovation efforts of the past decades have failed primarily because of this - and not, as is often assumed, because of "wrong" innovations, even though there have undeniably been undesirable developments.

From the outside, the demographic change in European societies also affects the railway sector. Low birth rates, the impending retirement of the baby boomers of the post-war period, different models of upbringing and pronounced migration movements in Western Europe have led to structural changes in societies, the effects of which are reflected in the scarcity of qualified young people and in their significantly different socialisation compared to previous generations.

For the railway sector, this ongoing socio-demographic change means both opportunities and threats. With a replacement of the majority of skilled workers in the next two decades, it is in principle possible to shape the transformation of the rail freight sector, which is additionally favoured by the scarcity of personnel in questions of efficiency increase and automation. On the other hand, the rail sector is in great competition with other sectors and especially with the more non-state-owned sectors of the economy. An orientation towards being a service provider in a competitive environment requires a specific corporate culture that is attractive to appropriately oriented workers. However, these are very much in demand by all employers. However, the culture of the railway sector today is quite different, as has been pointed out above.

In this respect, the question is whether today's actors in rail freight can transform themselves to the extent required. There are currently no precedents for this in the case of state institutions and companies. There is therefore a strong case for opening up the rail transport sector to new private players who, through their actions, will gradually transform the sector and provide the arguments for today's actors, who are fundamentally willing to change, to become actively involved in this process and help shape it.

9.3 Risk Consideration of Migration Paths

The following subchapters address aspects that are essential for a successful timely migration of IP5 technologies and solutions and thus pose a risk to the implementation in case of non-availability.

In addition to the pure availability of the solutions, (poor) economic expectations of a technology represent a risk for the successful market introduction. The introduction of DAC can serve as an example here, whose potential can only be fully exploited when the entire existing fleet has been converted and thus the compatibility of all wagons with each other has been restored. And this immediately creates a conflict of objectives in terms of time and financial capacity of the private-sector or private-sector-organised stakeholder groups. An early realisation of benefits, e.g. through complete migration within a revision cycle of 6 years, would overburden the wagon keepers (investors) financially, infrastructure managers would have to create conditions in train formation facilities for the migration period to handle two incompatible coupling systems and the coupling manufacturers would be forced to create production capacities for a very short period of time, which would no longer be needed after 6 years. This does not seem reasonable or within the realm of possibility for any of these actors. From a purely economic point of view, the consequence can only be to significantly stretch out the migration phase. This stands in the way of the rapid unfolding of benefits.

As the sensitivity analysis in Chapter 7.2.3 shows, the efficiency lever of DAC is not only rather low compared to other technologies. In particular, higher distance efficiency and elimination of train formation processes (no shunting) show significantly greater effects. There is no doubt that DAC is an important technology, especially due to the associated electrification of the wagons, which enables CBM and functions such as tracking/traceability that are important for the end customer. Nevertheless, the sense of retrofitting the entire fleet should be reconsidered. It seems to make more sense to push the conversion where compatible wagons/groups of wagons are required and can be isolated from other parts of the fleet. For the production concepts P2P and CTL this is given by definition. For today's single wagon traffic or block train traffic with adaptation of the train configuration along a route, this is certainly a challenge. However, the additional benefit of DAC would then be directly for a transport task and thus economic deployment would be more likely. More on the risks of DAC introduction in 9.3.3 and the financial burdens in 8.5.

9.3.1 Infrastructure and Access Points to the Rail Freight System

As described several times at the beginning and confirmed by other studies, in addition to the improvement of the range of services and the value proposition, another pivotal point for growth and market share gains of rail is accessibility to the system. It is imperative to reverse the current trend of decommissioning infrastructure. Since the expansion of the entire rail network (creation of new track lines) – as concluded in Fr8Rail D1.1 – is considered extremely unlikely for budgetary reasons, the focus of infrastructure development must be on the creation of new access points – especially for intermodal transports.

On the one hand, the existing terminals are not sufficient in terms of numbers and on the other hand, they are clearly limited in terms of loading track lengths for the handling of fixed block trains, which would again require additional – actually avoidable and time-consuming – coupling procedures and train formations with corresponding integrity checks. The following table shows an example of the track lengths of the craneable loading tracks of the DUSS terminals in Germany. Only the cells marked in green represent loading tracks that can handle a complete train with a total length of 680 metres. On all other loading tracks (marked red), complete handling is not possible; the block trains have to be dismantled for this.

Table 10: Loading track lengths of the DUSS terminals in Germany

	Usable crane length per track (m)													
name of terminal	track 1	track 2	track 3	track 4	track 5	track 6	track 7	track 8	track 9	track 10	track 11	track 12	track 13	track 14
Augsburg	240	200	110	100	65									
Basel, Weil am Rhein	645	645	645	645	550	550								
Beiseförth	345	345	345	345										
Duisburg	750	680	680	680	680	680	600	600	600					
Duisburg KV-Hub Rhein-Ruhr	710	710	710	710										
Erfurt-Vieselbach	380	380	380											
Frankfurt/Main-Ost	660	660	660	660										
Göttingen	256	256	256											
Großbeeren	700	700	350	350										
Hamburg-Billwerder	720	720	720	720	680	680	680	680	585	585	585	585		
Hannover-Linden	160	160	160	160										
Ingolstadt	350	300												
Karlsruhe	480	480	480	480										
Köln Eifeltor	700	700	700	700	700	700	700	700	700	700	700	700		
Kornwestheim	700	700	700	700	625	625	625	625						
Landshut	260	210	210	175	70									
Leipzig-Wahren	700	700	700	700	700	700	700	700						
Mannheim-Handelshafen	700	700	700	700	550									
München-Riem	700	700	700	700	700	700	700	700	700	700	700	700	700	700
Regensburg-Ost	490	490	490	490	445									
Stuttgart Hafen	600	600	600											
Ulm	700	700	700	700										
Wuppertal-Langerfeld	630	630	630	630										

This means that the existing terminal infrastructure must also be expanded if gross transport times (and are of importance to customers) are to be reduced. In addition to adapting the track length (if location and available space allow), expanding the parking areas for loading units can also be important. This is relevant for implementing the long-haul and shunting locomotive as mentioned in chapter 10.3.

At this point, a more in-depth study is recommended for the conditions in other European nations, based on the current traffic flows of containerised transports.

9.3.2 Approval of Technologies, in particular Rolling Stock

As IP5 aims to significantly improve the overall system in order to give new impetus to rail freight transport, IP5 will also develop technologies or overall solutions that go beyond the current state of the art. Consequently, it must be assumed that approval procedures will be required to which the previous regulatory framework and/or the scope of validity according to UIC may not be applicable. Thus, special approval requirements represent a risk for the implementation.

This has been taken into account at an early stage, for example for the concept of EMW as a non-UIC wagon concept, in that the regulatory framework is examined in the FR8RAIL III project. In addition to the analysis of the TSI rules regarding their relevance for the approval of the EMW for operation in the EU, a suitable approval concept for the EMW and the train composition based on the TSI will be developed and discussed with relevant Notified Bodies, selected national supervisory authorities such as EBA, BAV,... and the European Railway Agency. This should ensure that an appropriate approval concept is already available with the production of the first prototype.

9.3.3 Standardisation of the Digital Automatic Coupling

Since 2018/2019, four coupler manufacturers CAF, Dellner Couplers, J.M. Voith and Wabtec Europe have been developing prototypes of a DAC type 4. However, the four manufacturers are using different types of automatic couplers as a basis - both with regard to the coupler head, but also for other components of an automatic coupler, such as shock-spring elements, for example.

While CAF is developing a DAC based on an SA3 coupler within the framework of Shift²Rail, Wabtec Europe has decided to develop a DAC based on a Schwab coupler head. Dellner Couplers as well as J.M. Voith in turn build their prototype development on a design with a Scharfenberg coupler. All four manufacturers made a conscious decision for the selection of the coupler head based on the advantages and disadvantages of the above-mentioned coupler designs - but arrived at different assessments in their selection.

In fact, there are significant advantages but also disadvantages for all of the coupling types presented in the BMVI study on DAC. The study itself comes to the conclusion that a direct selection of a standard DAC on the basis of a theoretical evaluation is not expedient and that the above-mentioned coupler types should rather be checked for their applicability and suitability for everyday use in rail freight transport.

According to the study, this must be accompanied by a sector-wide agreement process, the aim of which should be to standardise a standard DAK including all relevant interfaces throughout the EU, as well as to adapt the TSI WAG, TSI LOC&PAS and TSI OPE within the framework of a regulation, so that a DAC can be certified as an interoperability component by the Notified Bodies.
For this purpose, the authors propose essential steps to be taken:

- Develop the basis for the development, testing and assessment of a DAC;
- Conduct DAC tests/demonstrators and select DAC type;
- Standardisation of DAC;
- Certification of DAC as an interoperability component.[61]

Both the agreement process for the cross-stakeholder selection of a coupling type and the last two points have an enormous barrier potential. This is particularly relevant for the time dimension and also for other supporting technologies/solutions for the envisaged digitalisation and the subsequent key technologies (see Figure 25, page 67).

The following Figure 34 shows barriers identified by the German DAC study. In addition, Figure 35 clearly assesses the strength of the barriers.

[61] BMVI study an DAC, detailed explanation there in chapter 5.2

1 Technology	**2 Operation**	**3 Financial**
1. Lack of standard for the DAC 2. Lack of standard for the electrical power supply 3. Lack of standard data communication in the train 4. Lack of proof for the reliability/availability of the DAC 5. Lack of approval for the DAC 6. Lack of inspection standard for legal requirements in the transport of hazardous goods, esp. electrical power supply	1. Additional costs for parallel operation of the DAC / screw coupling 2. Lack of migration planning regarding the order of freight wagon conversion 3. Lack of non-discriminatory and seamless availability of adapters / coupler wagons	1. Lack of proof of the business case for the DAC plus further automation elements 2. Long payback period for investment in DAC 3. Unequal distribution of costs / benefits (investment by wagon keepers, benefits mainly for RUs) 4. Lack of financial strength in the sector to make investments in DAC

4 Policy	**5 RFT sector**	**6 Industry** / **7 Personnel**
1. Lack of a European agreement process for the DAC migration 2. Lack of a financial support programme for the sector in the DAC migration	1. Lack of commitments from all relevant stakeholders on the migration to a DAC 2. Lack of organisational structures for migration to the DAC (e.g. European coordination office)	**6 Industry** 1. Market prices for DAC not yet known 2. Lack of production and conversion capacities for the DAC **7 Personnel** 1. Lack of a training concept 2. Agreement on DAC with works councils / trade unions still pending

Figure 34. Barriers to implementation for the DAC migration[62]

Barriers to implementation and difficulty rating (low - very high)	Low	Moderate	High	Very high
1.1 Lack of standard for the DAC		●		
1.2 Lack of standard for the electrical power supply			●	
1.3 Lack of standard for data communication			●	
1.4 Lack of proof for the reliability of the DAC		●		
1.5 Lack of standard for the DAC	●			
1.6 Lack of testing for DAC with regard to hazardous goods			●	
2.1 Additional costs for parallel operation of the DAC/SC		●	●	
2.2 Lack of migration planning for the DAC	●			
2.3 Lack of availability of coupling wagons/adapters		●		
3.1 Lack of proof for the DAC business case			●	
3.2 Long payback period for the DAC		●		
3.3 Unequal cost/benefit distribution for the DAC			●	
3.4 Lack of financial strength in the RFT sector				●
4.1 European political agreement on the DAC		●		
4.2 Lack of financial support by political bodies			●	
5.1 Lack of commitments from all relevant stakeholders				●
5.2 Lack of organisational models		●		
6.1 Market prices for DAC not yet known		●		
6.2 Lack of production/conversion capacity		●		
7.1 Lack of a training concept for personnel	●			
7.2 Coordination with employee representatives still pending		●		

Figure 35. Barriers to implementation – Difficulty rating[63]

[62] BMVI study, Development of a concept for the EU-wide migration to a digital automatic coupling system (DAC) for rail freight transportation, June 2020, p. 152

[63] BMVI study, Development of a concept for the EU-wide migration to a digital automatic coupling system (DAC) for rail freight transportation, June 2020, p. 152

The authors identify two obstacles in particular as extremely critical:

- Insufficient financial strength in the rail freight transport sector and
- Lack of binding participation of all relevant stakeholders.

In addition to considering all technical, operational, industrial and personnel-related issues, the authors recommend focusing, at least in the short term, on establishing consensus in the sector on the introduction of a DAC.

According to the study, the multitude of obstacles listed above clearly show that the introduction of a DAC in the EU-wide SGV is an ambitious and extremely complex project. A great deal of effort would be required to create all the preconditions for the migration of a DAC. However, the DAC also holds considerable potential for the rail freight business, especially as an enabler for further digitalisation and automation.

The excerpts from the study make it clear that the timely introduction of a standardised DAC is by no means a given and is associated with considerable risks - but only if the existing production concepts and thus the complete compatibility of the entire wagon fleet with each other are strived for.

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However, this is not necessary if the proposed P2P and CTL production concepts with fixed train configurations are to be implemented. And the electrification and implementation of telematics applications is also feasible without DAC in these concepts. Certainly, under the given infrastructure conditions of the terminals, it is helpful to initially integrate a DAC into the train configurations to enable disassembly at short loading tracks. However, a standardised and sector-coordinated solution is not necessary for this either. It is much more important that type 5 (i.e. also automatic uncoupling, remotely) is implemented immediately with the market launch of a DAC in order to fully exploit the potential.

In principle, a standardised DAC is required for the upgrade of today's single wagon traffic to OTL. Only in this production scheme will the preservation of wagon compatibility among each other be purposeful.

9.3.4 Basic Time Availability of Standards for supporting Technologies/interim Solutions

Basically, the categorisation of the various technologies into evolutionary, bridging and revolutionary approaches results in possible availability and implementation risks. The interrelationships and dependencies of single solutions on the availability of the so-called supporting technologies were presented in chapter 8.2 and Figure 25. It is clear from this that not a few solutions have to be fully developed to give the sector new impetus.

Take the electrification of freight wagons: simply putting electric power on the wagon is of no immediate use. But it is crucial for the implementation of digital technologies such as condition-based maintenance; telematics applications that enable the tracking of loads; the fully automatic train integrity check Safe-Train-Integrity or simply offers the possibility of locally emission-free refrigerated transport by rail. With these few example applications, very important success factors are addressed:

- CBM reduces unforeseen failures, optimises maintenance/maintenance increases the reliability of the overall system.

- Telematics applications bring transparency for the customer and other stakeholders
- Safe Train Integrity reduces process times, increases efficiency
- Cooling options address a new market segment/customer needs.

The red path in figure below (excerpt from Figure 25) graphically illustrates the interrelationships once again.

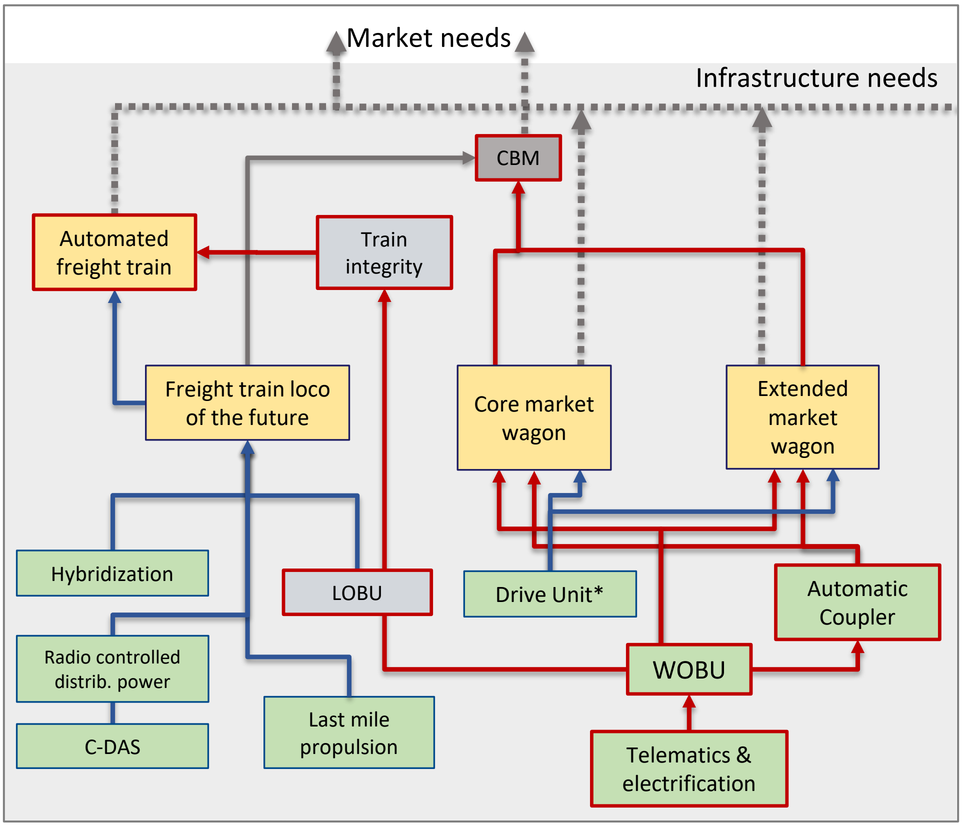

Figure 36. Technology Pathway Electrification - WOBU - STI - CBM/ATO

Therefore, the need for standardisation of the power supply on the one hand and standardisation as well as compatibility of the communication systems on the other hand must be pointed out.

For intrasectoral applications (e.g. train communication systems, WOBU), new standards can/must be developed. Uniform communication protocols and data structures are required so that the data of the different applications can be exchanged and processed accordingly.

In the case of intersectoral applications - for example, data transmission for logistics applications - it should be possible to fall back on standards established there or to be served via corresponding interfaces. It cannot be expected that logistics, which is dominated by road freight transport, will be forced to adapt to new rail-related systems.

Thus, for the successful establishment of new applications, such requirements must be taken into account. Especially when standardisation is done before a market launch, it means a coordination process involving several parties. This takes a lot of time, as it requires coordination and agreement among the relevant stakeholders on an application/system often without market proofing.

10 Getting started – reasonable initial Packages for Market Uptake

In the previous chapters, the innovations of Shift2Rail were discussed in the context of the competitiveness of the entire rail freight sector. The picture that has manifested itself is that the current rail freight transport system can be improved, but the effects are not sufficient to sustainably improve the competitive position of rail compared to road in such a way that a shift of a substantial transport volume to rail becomes attractive from the customers' perspective.

For the market launch of the solutions developed in S2R IP5 a transformation of the entire system is therefore required - both technically and operationally. This can only be implemented without painful, major upheavals with a combined evolutionary and revolutionary approach over a longer period of about 20 years, in which the existing system is further improved within the framework of a reasonable economic consideration and at the same time nuclei are laid for future production concepts. In the course of the market ramp-up, these innovation islands will then be consistently expanded and further developed and thus displace the current system over the aforementioned time period. (see Figure 37)

It is important to note that both systems will coexist for a longer period of time and will not be compatible with each other. The intermediate steps and the speed in individual phases are difficult to predict. Much will depend on how quickly elements of the new production system can be realised and even more on how quickly they are taken up by the transport market. In chapter 8.6 it could be shown that this migration concept also has a very beneficial effect on the capital requirements in the sector, which reduces the hurdles for its implementation.

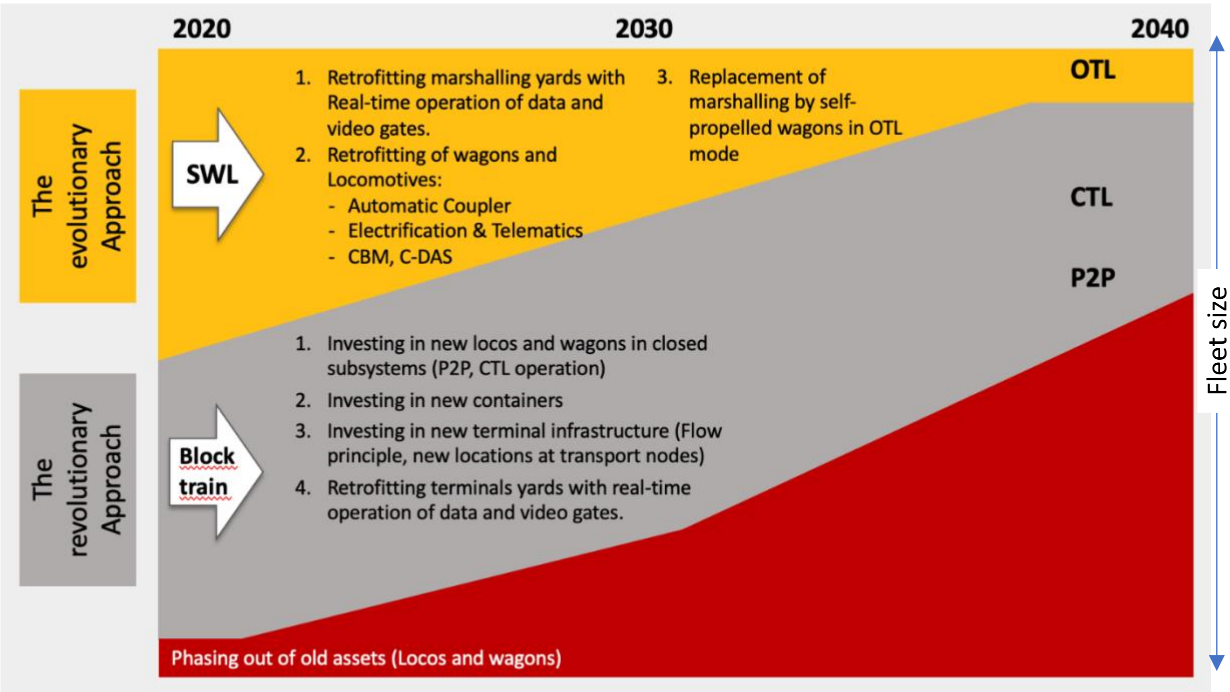

Figure 37. Market uptake: Transformation of the rail freight system along a "process of displacement"

The final question is how to get started with the migration process. This concerns both individual technical measures and the use of the previous infrastructure for the changed production systems.

For the market uptake, therefore, measures were selected that are highly relevant for the efficiency of the P2P and CTL production systems on the one hand, but which can also be used sensibly for an improvement of the current production systems and without major hurdles or dependencies for their introduction.

As market launch packages were selected:

- The automatic centre coupling
- The electrification of freight trains
- Block train with combined long-haul/shunting locomotive and EMW
- The intelligent video gate IVG and
- City terminals, which are intended to improve rail access with containers directly into the cities.

10.1 The Coupling Package

The automatic centre coupling not only has advantages in terms of driving dynamics and weight, but also significantly increases safety and efficiency in train formation, provided that the media required in the course of electrification and digitalisation are also automatically included in the coupling process. This is the case with the coupling types from type 4 onwards, whereby type 5, which can also uncouple automatically and remotely, is to be preferred in terms of efficient train formation.

The technical features are sufficiently described in the Shift2Rail projects FR8RAIL and elsewhere [citations refer to documents FR8RAIL D5.1, D5.6]. Furthermore, the fundamental advantage of a Europe-wide standardised solution for the coupling is beyond question, although this is not mandatory for all applications. Even if the majority of the European freight wagon fleet is registered for general use in the UIC system (AVV), this does not automatically mean that the wagons are arbitrarily mixed with each other in practical use. In fact, there are a number of transport operations for which this does not apply and their compatibility requirement today is primarily related to the equipment of the locomotives because there are hardly any fixed assignments between locomotives and wagon groups today.

That this does not have to be the case is shown by the results in FR8RAIL on production systems (see reference document D1.2 Top level requirements, development of technical specifications for Wagon application). The proposed production systems Point-to-Point (P2P) and Closed-train-loop (CTL) allow an allocation of locomotives to wagon fleets and by definition reduce the train formation itself. Nevertheless, these two applications for combined transport require regular partial train splitting to a certain extent in order to take into account the limited track lengths in many sidings and terminals. Nevertheless, the production processes offer an interesting scenario with which a sensible first step can be made in the conversion of European rail freight transport to automatic coupling.

The basic problem with the introduction of automatic coupling into today's freight transport system is that the coupling removes the compatibility of the vehicles in the UIC system and thus permanently disrupts today's production system, which is based on recurring train formations, because a second independent compatibility parameter must be introduced into the system. The resulting mixed system reduces the efficiency of the overall processes until the majority of vehicles have been equipped with the new coupling.

This is the reason why the DAC is counted among the bridging technologies in chapter 8.1 - the significant economic and process-related effects only occur when almost the entire system has been converted. This period can be estimated to be at least 6 - 8 years in the existing stock, which is derived from the schedules of today's maintenance concepts based on fixed deadlines for the major overhaul. Deviating from this would entail further follow-up costs.

It would also be completely unclear where the capacities in the infrastructure and workshops for a short-term changeover would come from and what would happen to these capacities afterwards. This view is generally accepted in the sector (reference study BMVI “Development of a concept for the EU-wide migration to a digital automatic coupling system (DAC) for rail freight transportation”[64]).

All this creates an overall economic problem because the potential investors, which are currently the wagon keepers due to the ownership structure, would have to pre-finance the later return phase over a long period of time by converting their fleets. With the usual amortisation calculations, even with low assumed interest rates for the capital invested, one quickly ends up with amortisation periods of 14 or more years, as was shown in the BMVI study on DAC[65]. With today's understanding of investors, this result is tantamount to saying that the investment does not yield a return, but in no case can it be backed by significant amounts of equity capital. Especially since the question of the lifetime of the coupling and its repair costs, which have not yet been adequately considered in the known calculations, is gaining in importance with these long periods of time.

This raises the question of how and with which scenario automatic coupling could be introduced under purely economic considerations. If we return to the idea formulated at the beginning, in which it was stated that by no means all vehicles have to be fully compatible with each other, one possibility would be to sort the stock into clusters of fleet interoperability and start with the clusters where there are no interactions with other clusters. These are naturally mainly the groups of wagons that are used in combined transport and in factory traffic. However, this allows more than 50 % of the transport performance to be recorded in tonne-km. Single wagon load traffic has more frequent coupling operations, but also forms the largest cluster - an economic amortisation of the introduction of DAC in the migration phase is therefore hardly possible because, as explained above, the return on investment only sets in very late and, moreover, further efforts in the train formation plants/marshalling yards have to be solved in the migration phase.

10.2 The Electrification Package

Solutions in the sense of digitalisation, which are based on the collection of data and their use and transmission, presuppose an intelligence of the train and its components - i.e. of wagons and locomotives - in terms of logistics and operational performance. However, this is not conceivable without an appropriate power supply.

A uniform design of the power supply - although not absolutely necessary for many applications - lends itself to the uniform design of the locomotives' auxiliary converters. The power supply should not only cover the requirements of the necessary control and instrumentation technology, which is comparatively small with digital-electronic solutions, but also provide power current to operate drives such as cooling units for combined transport or movable superstructures. A solution based on 400 V three-phase current is therefore to be preferred in order to be able to fall back on standard components from the industry. The railway sector cannot come close to the quantities usually demanded there. The development of own solutions with deviating voltage levels is therefore not an

[64] Study and additional documents available at www.bmvi.de/DAK-Studie
[65] BMVI study, Development of a concept for the EU-wide migration to a digital automatic coupling system (DAC) for rail freight transportation, June 2020

option, because the necessary allocation of development costs to comparatively very small numbers of units would again burden the sector.

From a migration point of view, the question of a sensible introduction strategy naturally arises. Since electrification requires the transmission of energy in the entire train set and the benefits of digitisation for many areas can only be realised in a meaningful way across trains, but this in turn requires a universal solution in the train set, the equipment strategy would be to implement electrification and automatic coupling as an integral migration step. This would mean that the level 5 DAC discussed in the previous chapter could also be implemented immediately. A level 4 solution of the DAC could be dispensed with.

The question of compatibility does not arise at this point because the solution discussed here is not compatible with today's freight wagons. This circumstance cannot be solved by any intermediate adapters. Therefore, it remains with the application-related migration approach already discussed in the previous chapter on coupling and not a fleet- and vehicle-related approach.

10.3 Real Block Train with the Long-haul and Shunting Locomotive (Lh-S) and EMW

Increasing the competitiveness of rail in freight transport is, in view of the levels presented by road, above all a question of

- efficient processes,
- accelerated service provision, as well as the accompanying
- improved utilisation of the necessary investments respectively assets.

All three aspects can be served with the approach of a combined long-haul/shunting locomotive, with the shunting operations that are certain in the new production systems and which, due to the infrastructure, also become necessary in with the new production systems where the available track lengths allow for loading and unloading operations for the entire train formation. This is the case, for example, at several terminals but not all terminals for combined transport today (see chapter 9.3.1).

In the case of rapid transhipment and/or train changes, the operationally necessary journeys can be carried out with the long-haul locomotive if it has drive equipment that does not require an overhead line, as this is often not found in the shunting areas or is not even permitted, as in the case of vertical craning in combined transport.

The overview below shows a representation with the possible drive variants for this application.

From the point of view of purely electric operation and low investment costs, everything speaks in favour of the variant of an E-Locomotive with battery storage. Its low range is not disadvantageous for the combined long-haul/shunting locomotive (Lh-S Locomotive), as the energy requirement for shunting is low. If the application of the train set requires longer distances in areas which are not electrified yet, then of course a hybrid locomotive with diesel engine is preferred. In the future drives with Fuel Cells can be used also.

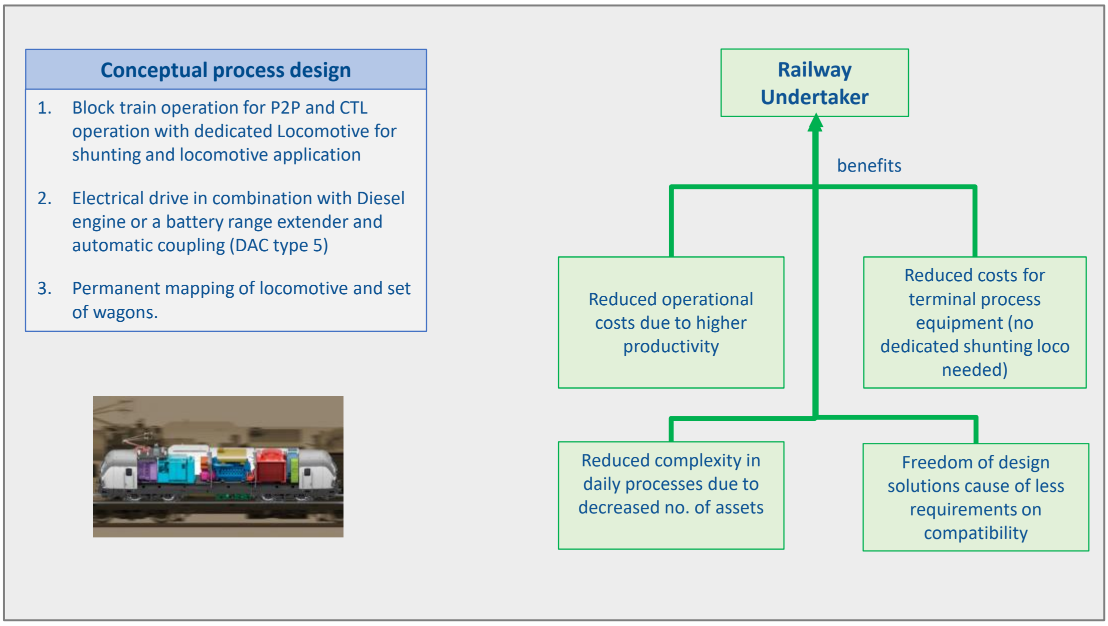

Figure 38. Concept for integrated Long-haul/Shunting Locomotive

The economic advantage for the sector is a significantly reduced need for locomotives. This also influences the equipment costs for train protection with ETCS, that will also support shunting and other operational movements in the future. The initial equipment or retrofitting thus extends to significantly fewer locomotives.

The same applies to the equipment with automatic coupling (DAC) as well as the Safe Train Integrity System (STI), so that the Lh-S-Locomotive approach should be sensibly carried out right at the beginning with the introduction of other technologies for future rail freight traffic in order to limit the scope.

The time advantage and better utilisation of the investments are evident, as shunting can be carried out directly with the Lh-S-Locomotive. It is no longer necessary to have a separate shunting locomotive with another driver. This means that also personnel costs can be reduced in the future, which is necessary anyway in view of the demographic development and the resulting scarcity of this resource. Nevertheless, it may be necessary that the change of locomotive driver is required.

The sector can use the solution presented in Shrift2Rail IP 5 in the form of the "Locomotive of the future" at any time. All that is required is an agreement on the operational process between the railway undertaker, infrastructure manager and terminal manager.

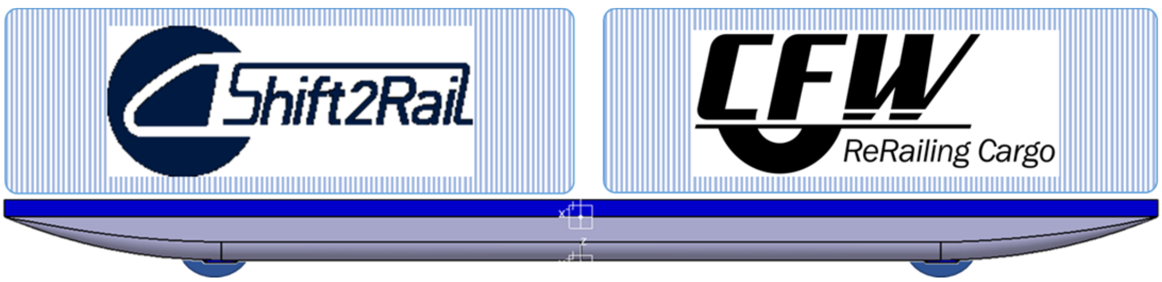

Figure 39. EMW based train concept

The other element for entering the P2P and CTL business, the wagon for more efficient intermodal use, harmonises perfectly with the locomotive concept presented, as the fixed connection of locomotive and wagon promises high efficiency in operation. The EMW promises a significantly higher loading capacity in terms of containers per train, lower energy consumption, significantly better braking dynamics and a higher maximum speed, so that the range of services offered by rail freight transport as well as efficiency can be significantly increased.

10.4 Intelligent Video Gates

The intelligent video gate is, at its core, a detection algorithm that can identify or detect wagons, cargo and their external condition via optical measurements. In its simple application, it is only used to detect the entry of wagons into terminals and train formation facilities. This can be extended from simple deductions of the condition around e.g. damage to the vehicle or load to integrity checks during train formation. Thus, the video gate is relevant for today's production systems as well as for future concepts, albeit to a different extent. Furthermore, its application does not encounter any significant barriers to market entry. The technology in general is available and can be developed independently via more powerful algorithms.

The emergence of new technologies and their corresponding applications within intermodal and rail freight terminals enable improvements in efficiency in existing business processes, relieving them of manual activities and enabling higher degree of automation and digitalization. To initiate the next logical step to a higher level of automation in terminals and to reduce the lead-time needed for the identification and verification processes of freight trains, the concept “Intelligent Video Gates” (IVG) has been introduced and analyzed. The project has been bi-sectional, first describing functional and technical requirements and the selection of components (FR8HUB D4.1) and secondly carrying out a technical proof of concept (PoC) and introducing a roll-out and implementation plan (RIP) within a Swedish and German context (FR8HUB D4.2). The main technical components composing the Intelligent Video Gate are:

- Cameras and image processing
- RFID readers and tags
- Illuminators
- Sensors

The selection of components is depending on the real terminal characteristics, such as number of tracks, installation position, environmental conditions, train speed etc. Hence, albeit a technical proof of concept based on a model train has been carried, further work is needed to better test the components in relevant field environment and to highlight unexpected impacts. Thus, the next logical step in the project is a demonstration gate planned in port of Gothenburg, Sweden. Part of the analysis of the concept is carried out as a feasibility study based on *expected benefits* and *changes in costs.*

Establishing IVGs in intermodal terminals and freight yards can have several positive effects. From the perspective of Terminal Operators (TO) and Yard Managers (YM), the IVG concept would imply an improvement in operational efficiency, mainly due to:

- Faster arrival processes through deviation management and identification of wagons and loading units with higher degree of automation during arrival processes,
- More efficient and safer departure processes through higher degree of automation at departure.

- Improved internal operations and interface towards road haulers will be achieved when the sequence of wagons and loading units (LU) and any deviations from pre-notified sequence are known in advance

From perspective of the railway and road infrastructure managers (IM), the IVG concept would mean improvements mainly regarding:

- An improved interface between freight nodes (terminals and rail yards) and the rest of the railway network.
- Control and monitoring of dangerous goods and strategic points in the railway network, e.g. at tunnels where the knowledge of the location of dangerous goods is very important as well as at border crossings.

IVGs would provide future opportunities for improved monitoring of safety controls of wagons and LUs, primarily with regards to damages and that LUs are properly attached to the wagons e.g. that the semi-trailer's kingpin is positioned correctly in the wagon. The IVG could also facilitate the customs process, in terms of handling documentation and identification as well as opportunities of sealing LUs. When studying the benefits and added value that the two technologies, image processing and RFID will imply, they are considered as good complement to each other. The image processing can read codes and placards of dangerous goods without extra equipment on the wagon or LU, unlike other technologies, where RFID requires that the units are pre-installed with tags. The camera can also be used for other purposes than purely detecting and identifying devices, such as damage inspection and departure control. Other operational functions at terminals and yards could also be improved through automatic identification of wagons and LUs. Improved services at terminals would imply an improved and more attractive range of services, which in the long perspective should lead to a higher degree of customer satisfaction. Figure 40 illustrates the main identified benefits of the IVG concept.

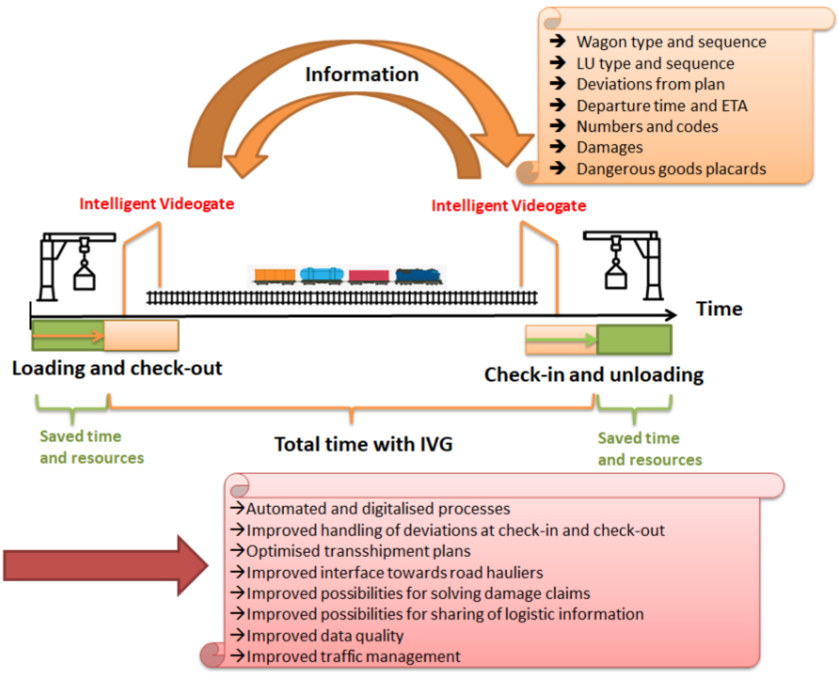

Figure 40: The main identified benefits of the IVG concept.

Data (orange box) that can be identified and benefits (pink box) that it can lead to.

The costs for the constituent components are in many cases very difficult to pinpoint and monetize, depending on local cost structures and the design of the concept regarding e.g. single or double track construction and the number of cameras. However, the main cost components of the system have been identified and their expected changes regarding installation and variable costs are estimated and presented in full in[66].

Costs related to the implementation of an IVG are mainly focused to the initial costs for the gate's physical construction and the IT-system needed. The terminal management system should be prepared for the communication with an IVG including updates in hardware (e.g. exchange server) and software (e.g., data exchange converter) as well as training for staff, software licenses, support costs and potential fees for using a common information-exchange platform. Expected reduction in costs are initially related to less time spent on manual inspections along trains during arrivals, within the terminal/yard and during departure, offering new opportunities for businesses and planning due to increased level of automation and possibilities for optimisation of operational processes.

As for the migration of the concept, parts of it have already been introduced to the market e.g. RFID readers at shunting yards and OCR applications at terminals and yards. However, in order to highlight the potential of the integrated system, including data sharing and data exploitation, a physical installation of a demonstration gate is planned to be constructed in the next phase of the project in the framework of FR8RAIL III. As for selection of components, the set of IVG-components and functions must be selected and designed to fit into an overlapping framework of the terminals. Still, work in this project and in the following one will better test the components in laboratory and in relevant environment, highlighting unexpected positive or negative characteristics.

Another important consideration is that the design also is depending on the real terminal characteristics, such as number of tracks, installation position, environmental conditions, etc. A different component may be preferred to another one, even if the latter had a better evaluation score for the theoretical scenario. As a conclusion, the main objective of the selection process is the process definition itself, together with an exemplification on a theoretical scenario, providing indications to further testing and site rollout activities.

[66] D4.2 Technical Proof of Concept and Roll-out and Implementation Plan, FR8HUB, 2019

10.5 City Terminals

Shifting the modal split in favour of rail is not only a question of more efficient use of the railway system, but also of a more developed infrastructure. The latter is essential for shifting traffic that is currently handled by road. Without an attractive linking of the rail infrastructure with the higher-level logistics chains of land transport, there is little chance that traffic will be shifted to rail to any significant extent.

The P2P and CTL production methods from FR8Rail 1, which were explained in Chapter 4.4. and from which the majority of the modal shift is expected, can only achieve their effect in the transport market if there are attractive transfer points between rail and road. This requires additional and highly efficient terminals in the area of nodes, sources and sinks of goods flows. Linking up with the logistics systems in conurbations and large city centres seems particularly interesting. Through a clever arrangement in their centres, the goals of conurbations with regard to traffic congestion and pollutant emissions can be effectively supported.

It is therefore obvious that in large cities and conurbations, terminals for the transhipment and distribution and bundling of goods are built as city terminals with integrated storage and sorting and picking zones, which allow rail to connect directly to the centres. Figure 41 gives an idea of how this could be designed to realise integrated urban logistics.

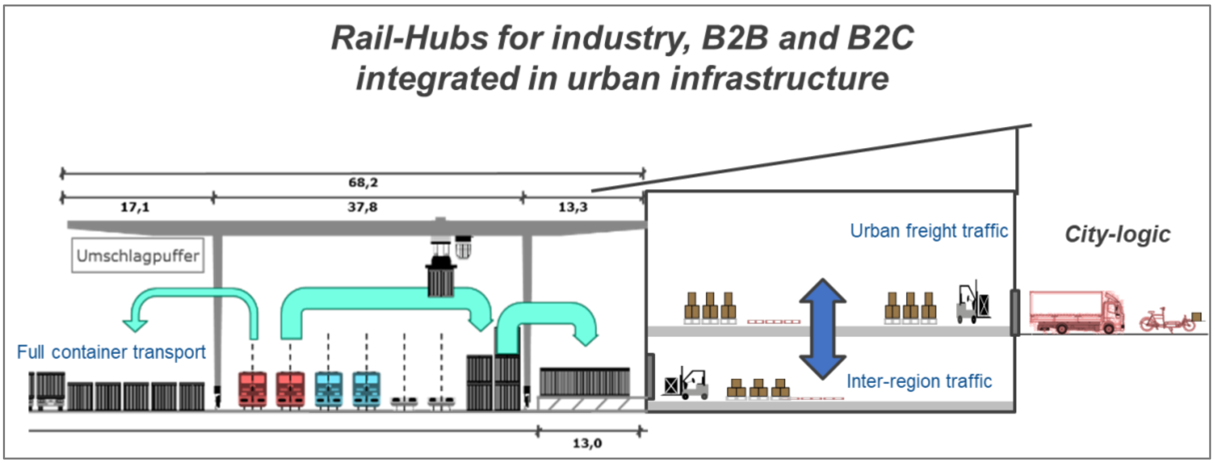

Figure 41: Urban logistic with Rail Hub

11 References

ARCC	Official project proposal
ARCC	D1.3 - Automated Brake Test
ARCC	D2.2 - Description of business processes of a network management system and the interactions/interfaces with a Real-time Yard Management System
ARCC	D2.3 - Modelling Requirements and Interface Specification to Yard Simulation System
BMVI DAC	German study on DAC initiated by the Federal Ministry of Transport and Digital Infrastructure
DUSS	Key facts of German terminals, duss.de
FR8HUB	Official project proposal
FR8HUB	D3.1 - State-of-the-art and specification of innovations, demonstrations and simulations
FR8HUB	D4.1 Description of functional and technical requirements and selection of components, 2018
FR8HUB	D4.2 Technical Proof of Concept and Roll-out and Implementation Plan, 2019
FR8RAIL	Official project proposal
FR8RAIL	D1.1
FR8RAIL	D1.2 Top level requirements, development of technical specifications for wagon application
FR8RAIL	D5.1 - State of the Art on Automatic Couplers
FR8RAIL	D5.6 - Migration Plan for Automatic Couplers
FR8RAIL 2	Official project proposal
Spectrum	Deliverable D1.1 Logistics and market analysis - Interim Report
Spectrum	Deliverable D1.3 Logistics and market analysis - Final Report